Journal

of

THE ROYAL AERONAUTICAL SOCIETY

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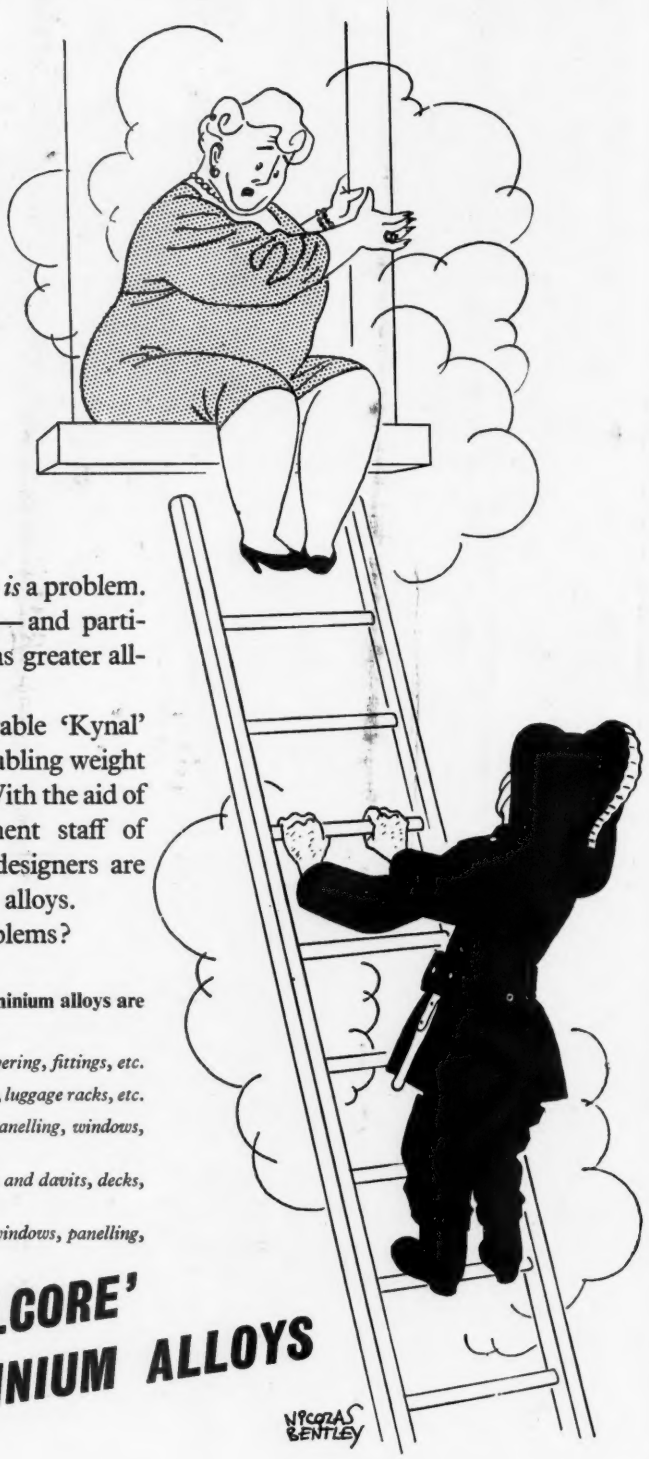

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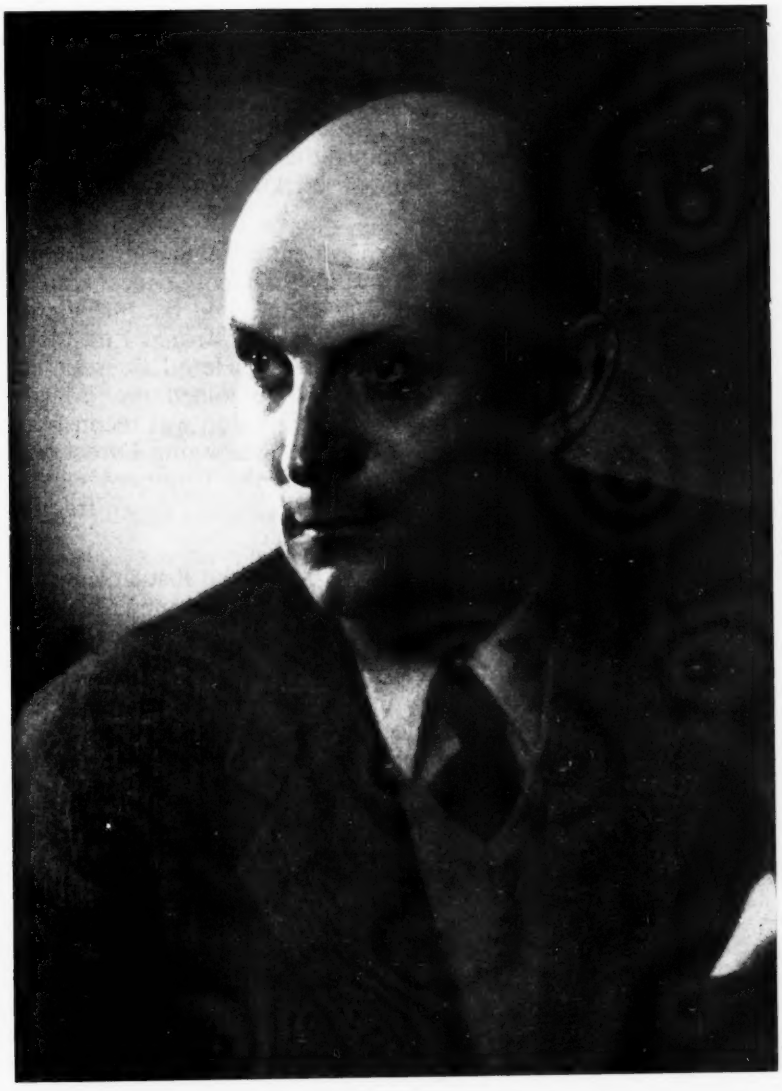


SIR GEORGE EDWARDS, C.B.E., B.Sc., A.M.I.Struct.E., *Fellow*

President 1957-8

SIR George Edwards was born in Essex on 9th July 1908 and educated at the South-West Technical College and London University, where he took his B.Sc.(Eng.). After practical workshop and erecting experience in structural and general engineering, followed by design and stressing experience, he joined the Aircraft Industry in 1935 as a member of the design staff of Vickers (Aviation) Ltd. at Weybridge.

In 1940 he was appointed Experimental Manager, remaining in this post throughout the war. In 1945 Sir George succeeded Mr. Rex Pierson as Chief Designer at Weybridge. He became General Manager of the Aircraft Division of Vickers-Armstrongs Ltd. in 1953 and in the same year he succeeded the late Sir Hew Kilner as Managing Director. Two years later Sir George joined the Board of Vickers Ltd., and in that year the Aircraft Division was reconstituted as Vickers-Armstrongs (Aircraft) Ltd. As Managing Director, Sir George has continued to be responsible for the Company's overall technical direction. He learned to fly in 1946, having flown frequently over the years on test flights as a passenger.

He was created a Member of the Order of the British Empire in 1945 and a Commander of that order in 1952. His knighthood was announced in the 1957 New Year Honours List.

Sir George was elected an Associate Fellow of the Society in 1942 and a Fellow of the Society in 1946. He has been a member of Council since 1949 and was elected a Vice-President in 1950. In December 1948 Sir George delivered a Main Lecture in London on "Problems in the Development of a New Aeroplane," and in the following year he read a paper at the I.A.S. - R.Ae.S. Conference in New York on "Turbine-engined Transport Aircraft." He was awarded the George Taylor Gold Medal in 1948 and the British Gold Medal for Aeronautics in 1952.

Sir George takes office as President of the Society at the Annual General Meeting on 8th May, 1957.

NOTICES

Sixth Anglo-American Aeronautical Conference

The Sixth Anglo-American Aeronautical Conference will be held at the Metropole Hotel, Folkestone, from Monday 9th September to Thursday 12th September 1957. Details of the arrangements, together with an application form for enrolment, were sent to all members in February.

The following is the list of papers to be read:—

I.A.S. Papers

N.A.C.A. Research on V.T.O.L. and S.T.O.L. Aeroplanes —Marion O. McKinney, Jr., *N.A.C.A. Langley Aeronautical Laboratory.*

Control of Supersonic Propulsion Systems—Bruce T. Lundin and John C. Saunders, *N.A.C.A. Lewis Flight Propulsion Laboratory.*

Nine years' Experience with Titanium—Leo A. Schapiro and Emerson LaBombard, *Douglas Aircraft Co., Inc., Santa Monica Division.*

Blast Loads on Aircraft Structures—R. L. Bisplinghoff, and E. A. Witmer, *Massachusetts Institute of Technology.*

An Appraisal of Aeroelasticity in Design, with Special Reference to Aeroelastic Stability—Martin Goland, *Southwest Research Institute, San Antonio, Texas.*

Increased Useable Lift Through Boundary Layer Control —Charles W. Harper, *N.A.C.A. Ames Aeronautical Laboratory.*

The Role of Experimental Hyper-Ballistics in the Development of Future Aeroplanes and Missiles—Dr. Herman H. Kurzweg, *U.S. Naval Ordnance Laboratory.*

Aerodynamic Effects of Boundary Layer Unsteadiness— Franklin K. Moore, *Cornell Aeronautical Laboratory.*

R.Ae.S. Papers

The Electrical Control of Power Plants—G. M. Sturrock, *Ultra Electric Ltd.*

Some Aspects of Kinetic Heating of Aircraft Structures— J. Taylor, *Royal Aircraft Establishment, Farnborough.*

The Use of High Temperature Non-Metallic Materials— Dr. W. J. Strang and W. A. Baker, *Bristol Aircraft Ltd.*

Safety in Relation to Structural Damage—Dr. A. E. Russell, *Bristol Aircraft Ltd.*

The Presentation of Information by Aircraft Instruments —A. Stratton, *Royal Aircraft Establishment, Farnborough.*

Future Aerodynamic Shapes—P. A. Hufton, *Royal Aircraft Establishment, Farnborough.*

Small Nuclear Power Units—Dr. J. V. Dunworth, *Atomic Energy Research Establishment, Harwell.*

The Human Pilot as an Aircraft Operator—*Sqn. Ldr.* T. C. D. Whiteside, *Institute of Aviation Medicine, Farnborough.*

Members are reminded that applications for enrolment should be returned as soon as possible and that the closing date for enrolment is *31st July 1957.*

AGARD Wind Tunnel Panel

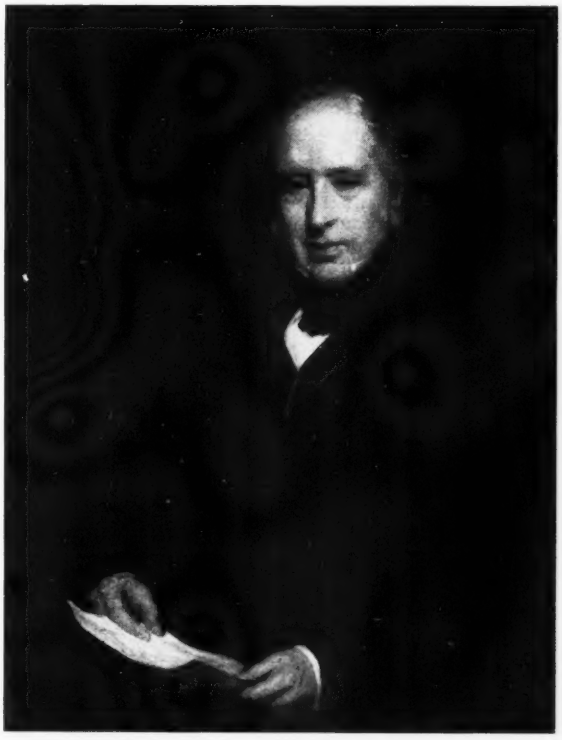
The Wind Tunnel and Model Testing Panel of the Advisory Group for Aeronautical Research and Development (AGARD) is sponsoring a meeting on hypersonic aerodynamics and testing facilities which will be held at Scheveningen, Holland, from 8th to 11th July 1957. The general subjects to be covered by the meeting will be theoretical work on hypersonic fluid mechanics, devices for hypersonic research, such as wind tunnels, gun-launched and rocket models. One day will be devoted to a discussion on shock tubes and their uses. Sixteen papers will be given.

Garden Party—15th September 1957

The Society will hold its Garden Party on Sunday 15th September 1957, following the Sixth Anglo-American Conference, at the Vickers-Armstrongs (Aircraft) Ltd. aerodrome at Wisley. Further particulars and application forms for tickets will be issued shortly.

Associate Fellowship Examinations

The Associate Fellowship Examinations will be held in the offices of the Society on the 18th, 19th and 20th June 1957. Full particulars will be sent direct to all Candidates.



Sir George Cayley, 6th Bart., 1773-1857. From the painting by Henry Perronet Briggs.

Sir George Cayley, Bart.

Until recently, the National Portrait Gallery possessed no portrait of Sir George Cayley. This curious omission has now been repaired by the generosity of the present baronet, Sir Kenelm Cayley, who has presented to the Nation the first of the Cayley portraits, that painted by H. P. Briggs. The date of the portrait is traditionally stated to be "circa 1841"; but Cayley was born in 1773 and it is hard to believe this is the face of a man in his late sixties. It seems more likely to have been painted about 1825-30.

The acquisition of this portrait of the "Father of Aerial Locomotion"—as Henson rightly called him—resulted from a friendly "agitation" by Mr. C. H. Gibbs-Smith, *Companion*, and other members of the Society.

High Altitude and Satellite Rockets

Details were given in the April Journal of the Symposium on High Altitude and Satellite Rockets, organised jointly by the College of Aeronautics, the Royal Aeronautical Society and the British Interplanetary Society, which is to be held at the College of Aeronautics on 18th-20th July 1957.

The following is the provisional Programme for the Symposium. The lectures will be followed by discussion, prepared and informal:—

Wednesday 17th July

7.0 p.m.—Symposium assembles.
8.30 p.m.—Informal reception.

Thursday 18th July

Lectures: Morning—Scientific Uses, Professor H. S. W. Massey, F.R.S., *University College, London.*
The Gassiot High Altitude Rocket, W. H. Stephens, *Royal Aircraft Establishment.*
Afternoon—Propulsion Problems, Professor A. D. Baxter, *College of Aeronautics.*
Design Problems, K. J. Bossart, *Convair-Astronautics.*
Evening—Film Show of Rocket Developments.

Friday 19th July

Lectures: Morning—Re-entry and Recovery—Two papers, Dr. W. F. Hilton, *Armstrong Whitworth;* Dr. N. C. Freeman, *National Physical Laboratory.*
Afternoon—Guidance, Instrumentation and Telemetry, Dr. A. W. Lines, *Royal Aircraft Establishment.*
Future Developments, Dr. L. R. Shepherd, *Atomic Energy Research Establishment.*
Evening—Symposium Dinner (Dress Informal).

Saturday 20th July

Morning and Afternoon—Exhibition.
Afternoon—Cricket Match—British Interplanetary Society versus Wharley End C.C.

Several other papers have also been promised from the United States.

Applications for registration for the Symposium and for further information should be made to The Warden, College of Aeronautics, Cranfield, Bletchley, Bucks. The closing date for registration is 29th June 1957, but as accommodation is limited applications should be made as soon as possible.

DIARY

LONDON

9th May

Main Lecture.—The First Lanchester Memorial Lecture. Dr. T. von Kármán. Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. 6 p.m. (Tea 5.30 p.m.)

14th May

Section Lecture.—Reinforced Plastics for Primary Aircraft Structures. W. A. Baker. Library, 4 Hamilton Place, London, W.1. 7 p.m.

28th May

Section Lecture.—Flight Instruments. F. W. Meredith. Library, 4 Hamilton Place, London, W.1. 7 p.m.

GRADUATES' AND STUDENTS' SECTION

15th May

Guided Weapon Research and Development. W. H. Stephens. Library, 4 Hamilton Place. 7.30 p.m.

30th May

Visit to Bristol Aircraft Ltd.

21st June

Summer Party. 8-11.30 p.m.

News of Members

W. G. Burrow (*Associate*), formerly with Armstrong Siddeley, has taken up an appointment as Test Engineer (Turbines) with Clarke Brothers Co., Olean, New York.

A. W. Cameron (*Associate*), formerly lecturer and Officer in charge Flying Training at the R.A.E. Technical College, is now Selection Officer for British European Airways.

W. G. S. Castle (*Student*), formerly at Handley Page, is now in the Design Office (Technical) in Ransome and Marles Ltd.

T. Martin Chalmers (*Associate Fellow*) has resigned from John Dalglish and Sons Ltd. to join the Group Development Department of Messrs. Richardsons, Northumberland, as Senior Engineer.

Bryan S. Clark (*Associate Fellow*) is now acting as the senior Representative in Europe of the Garratt Corporation of Los Angeles.

A. V. Cleaver (*Fellow*) has joined the Aero Engine Division of Rolls-Royce Ltd. as an Assistant Chief Engineer to supervise the engineering of the Company's Rocket Motor projects.

E. W. Cornford (*Associate*), formerly Experimental Liaison Engineer at Vickers-Armstrongs (Aircraft) Ltd., is now Defects Analysis/Test Engineer with Tiltman Langley Ltd.

F. Cumberland (*Associate Fellow*) is now Inspector in charge Aeronautical Inspection Directorate at Folland Aircraft Ltd., Hamble.

G. M. Cutler (*Associate Fellow*), formerly Chief Technical Engineer, Humber Ltd., Coventry, has been appointed Chief Engineer of the new Long Term Project Division of that Company.

A. Day (*Student*) has taken a post as Junior Engineer in the Structural Test Section of Avro Aircraft Ltd., Malton, Ontario.

P. C. Dunne (*Associate Fellow*) is taking up a position as Professor of Structures at the Instituto Tecnologico de Aeronautica of the Brazilian Air Ministry.

J. R. Finnimore (*Associate*) has recently been elected to Associate Fellowship of the Institute of Aeronautical Sciences.

Wing Cdr. H. R. Free (*Associate Fellow*) is shortly to give up the post of Atomic Weapons Staff Officer in Melbourne to take up a staff appointment in H.Q. Far East Air Force.

J. G. Gill (*Associate Fellow*) is now a Director and Vice-President of Operations, Canadian Steel Improvement Ltd., of the A. V. Roe Group of Canada.

V. Gokhale (*Graduate*), formerly in the Jig and Tool Drawing Office, is now Planning Engineer with the de Havilland Engine Co. Ltd., Leavesden.

H. T. Hill (*Associate Fellow*), formerly Assistant Director at the Royal Aircraft Establishment, is now Chief Development Engineer of Blackburn and General Aircraft Ltd.

J. O. Hitchcock (*Associate Fellow*) has been elected a Director of Henry Wiggin and Co. Ltd.

Miss M. Jones (*Associate Fellow*), formerly with the Ministry of Supply, is now with the Aerodynamics Department of the Douglas Aircraft Co., Santa Monica, U.S.A.

R. C. LeBosquet (*Companion*) is now Works Manager at the Chiswick Works of Bush Radio Ltd.

Flt. Lieut. R. C. Manocha (*Associate Fellow*), formerly at H.Q. Office of the Director General of Civil Aviation, New Delhi, has now been posted as Senior Aircraft Inspector, Government of India in the Northern Area, Safdarjung Airport, New Delhi.

P. G. H. Newton (*Associate*) has relinquished his appointment as Chief Engineer to General Motors Holdens Ltd. in Melbourne to become a member of the Executive Staff of that Organisation.

Squadron Leader W. P. Nicol (*Associate*) has been appointed Director of Civil Aviation, Singapore.

COLIN RODGERS (*Graduate*), formerly with Blackburn and General Aircraft Ltd., has joined Solar Aircraft Co. as a Mechanical Engineer.

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R. N. Stephenson, Esq., Slough
M. Lindsay, Esq., Finchley, N.3
Mrs. E. H. Dixon, Bognor Regis
D. N. Terry, Esq., South Croydon
W. H. Edmonds, Esq., Walthamstow, E.17
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Peter Warren Johnson
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John Halliday
John Kenneth Harvey (*from Student*)
James Oliver Hill
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John Geoffrey Lodge (*from Student*)
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John Lawrence Williams
Julian Wolkovitch (*from Student*)
Ernest Martin Woodhams (*from Student*)
Roger Wallace Randal Young

High Altitude and Satellite Rockets

Details were given in the April Journal of the Symposium on High Altitude and Satellite Rockets, organised jointly by the College of Aeronautics, the Royal Aeronautical Society and the British Interplanetary Society, which is to be held at the College of Aeronautics on 18th-20th July 1957.

The following is the provisional Programme for the Symposium. The lectures will be followed by discussion, prepared and informal:—

Wednesday 17th July

7.0 p.m.—Symposium assembles.
8.30 p.m.—Informal reception.

Thursday 18th July

Lectures: Morning—Scientific Uses, Professor H. S. W. Massey, F.R.S., *University College, London.*
The Gassiot High Altitude Rocket, W. H. Stephens, *Royal Aircraft Establishment.*
Afternoon—Propulsion Problems, Professor A. D. Baxter, *College of Aeronautics.*
Design Problems, K. J. Bossart, *Convair-Astronautics.*
Evening—Film Show of Rocket Developments.

Friday 19th July

Lectures: Morning—Re-entry and Recovery—Two papers, Dr. W. F. Hilton, *Armstrong Whitworth;* Dr. N. C. Freeman, *National Physical Laboratory.*
Afternoon—Guidance, Instrumentation and Telemetry, Dr. A. W. Lines, *Royal Aircraft Establishment.*
Future Developments, Dr. L. R. Shepherd, *Atomic Energy Research Establishment.*
Evening—Symposium Dinner (Dress Informal).

Saturday 20th July

Morning and Afternoon—Exhibition.
Afternoon—Cricket Match—British Interplanetary Society versus Wharley End C.C.

Several other papers have also been promised from the United States.

Applications for registration for the Symposium and for further information should be made to The Warden, College of Aeronautics, Cranfield, Bletchley, Bucks. The closing date for registration is 29th June 1957, but as accommodation is limited applications should be made as soon as possible.

DIARY

LONDON

9th May

Main Lecture.—The First Lanchester Memorial Lecture. Dr. T. von Kármán. Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. 6 p.m. (Tea 5.30 p.m.)

14th May

Section Lecture.—Reinforced Plastics for Primary Aircraft Structures. W. A. Baker. Library, 4 Hamilton Place, London, W.1. 7 p.m.

28th May

Section Lecture.—Flight Instruments. F. W. Meredith. Library, 4 Hamilton Place, London, W.1. 7 p.m.

GRADUATES' AND STUDENTS' SECTION

15th May

Guided Weapon Research and Development. W. H. Stephens. Library, 4 Hamilton Place. 7.30 p.m.

30th May

Visit to Bristol Aircraft Ltd.

21st June

Summer Party. 8-11.30 p.m.

News of Members

W. G. Burrow (*Associate*), formerly with Armstrong Siddeley, has taken up an appointment as Test Engineer (Turbines) with Clarke Brothers Co., Olean, New York.

A. W. Cameron (*Associate*), formerly lecturer and Officer in charge Flying Training at the R.A.E. Technical College, is now Selection Officer for British European Airways.

W. G. S. Castle (*Student*), formerly at Handley Page, is now in the Design Office (Technical) in Ransome and Marles Ltd.

T. Martin Chalmers (*Associate Fellow*) has resigned from John Dalglish and Sons Ltd. to join the Group Development Department of Messrs. Richardsons, Northumberland, as Senior Engineer.

Bryan S. Clark (*Associate Fellow*) is now acting as the senior Representative in Europe of the Garratt Corporation of Los Angeles.

A. V. Cleaver (*Fellow*) has joined the Aero Engine Division of Rolls-Royce Ltd. as an Assistant Chief Engineer to supervise the engineering of the Company's Rocket Motor projects.

E. W. Cornford (*Associate*), formerly Experimental Liaison Engineer at Vickers-Armstrongs (Aircraft) Ltd., is now Defects Analysis/Test Engineer with Tiltman Langley Ltd.

F. Cumberland (*Associate Fellow*) is now Inspector in charge Aeronautical Inspection Directorate at Folland Aircraft Ltd., Hamble.

G. M. Cutler (*Associate Fellow*), formerly Chief Technical Engineer, Humber Ltd., Coventry, has been appointed Chief Engineer of the new Long Term Project Division of that Company.

A. Day (*Student*) has taken a post as Junior Engineer in the Structural Test Section of Avro Aircraft Ltd., Malton, Ontario.

P. C. Dunne (*Associate Fellow*) is taking up a position as Professor of Structures at the Instituto Tecnologico de Aeronautica of the Brazilian Air Ministry.

J. R. Finnimore (*Associate*) has recently been elected to Associate Fellowship of the Institute of Aeronautical Sciences.

Wing Cdr. H. R. Free (*Associate Fellow*) is shortly to give up the post of Atomic Weapons Staff Officer in Melbourne to take up a staff appointment in H.Q. Far East Air Force.

J. G. Gill (*Associate Fellow*) is now a Director and Vice-President of Operations, Canadian Steel Improvement Ltd., of the A. V. Roe Group of Canada.

V. Gokhale (*Graduate*), formerly in the Jig and Tool Drawing Office, is now Planning Engineer with the de Havilland Engine Co. Ltd., Leavesden.

H. T. Hill (*Associate Fellow*), formerly Assistant Director at the Royal Aircraft Establishment, is now Chief Development Engineer of Blackburn and General Aircraft Ltd.

J. O. Hitchcock (*Associate Fellow*) has been elected a Director of Henry Wiggin and Co. Ltd.

Miss M. Jones (*Associate Fellow*), formerly with the Ministry of Supply, is now with the Aerodynamics Department of the Douglas Aircraft Co., Santa Monica, U.S.A.

R. C. LeBosquet (*Companion*) is now Works Manager at the Chiswick Works of Bush Radio Ltd.

Flt. Lieut. R. C. Manocha (*Associate Fellow*), formerly at H.Q. Office of the Director General of Civil Aviation, New Delhi, has now been posted as Senior Aircraft Inspector, Government of India in the Northern Area, Safdarjung Airport, New Delhi.

P. G. H. Newton (*Associate*) has relinquished his appointment as Chief Engineer to General Motors Holdens Ltd. in Melbourne to become a member of the Executive Staff of that Organisation.

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David Stanley Bateman
Richard Charles Beech
Colin Neville Bent
Kenneth Vincent Blanchard
Alan Victor Blundell
Beverley David Britton
Derek Morley Capey
John Edward Chacksfield
Brian William John Childes
David Christopher Dixon Coope
Peter Cowley
Derek Charles Crain
Sudhindra Nath Das
Vincent Gargaro
Gerald David Hammersley
Michael James Henry Harding
Richard Hayes
Dennis Anthony Howard
David Oriel Noel James
Roy Stewart Jordan
John Kessell
Gordon Alfred Kidd
Barry Charles Latter
Ronald Thomas Lewis
Graham Noel McDowall
Derek Gordon MacWilkinson
Michael Charles Martin
Balai Chandra Mukopadhyay
Peter James Musgrove
Brian Padgett
Jack Beresford Pearson
Laurence Herbert Pretty
Michael Harold Radford
John Raine
Michael Graham Shaw
Dion Clive Thomas
Peter Beckett Tucker
Henry Geraint Madoc Vaughan
John Albert Vaughan
Kenneth Valentine Watkins
Christopher Robin White
Maxwell Dean White
Leslie Allen Williams
Peter Willshire
Reginald Eric Winterborne
John Anthony Bartlam Wolfe
Gordon Peter Worgan

Companion

Wallace Barrie Dannatt Wardle (*from Student*)

Preprints of the S.A.E.

As members may have noticed, for some time the Library has received the Preprints of the Institute of the Aeronautical Sciences and a selected number of those of the Society of Automotive Engineers. The latter body has now generously undertaken to give all preprints for future S.A.E. Bi-Annual National Aeronautic Meetings and also the aeronautic papers in the S.A.E. Annual Meeting. It will be realised that these will form most valuable additions to the Society's Library and the action of the S.A.E. is greatly appreciated by the Council.

Aerodynamics in Russia

A translation has been prepared by J. R. Crean, Esq. (*Associate Fellow*) of the pamphlet issued to celebrate the 220th Anniversary of the Russian Academy of Sciences in 1945. This is a most interesting document which traces much of the history of aerodynamics in Russia.

New Prices for Journal Binding

We regret that because of increased costs in the printing and publishing trade during the past year, prices for the permanent binding of Journals have had to be increased for 1957. The new charges will be:—

Permanent Binding

1956 Volume (including packing and postage) £1 2s. 6d.

Previous Volumes (including packing and postage) .. .. £1 4s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to the Lewes Press and to the Society.

Self-Binder Cases

Self-Binder cases of the "Easibind" type to hold 12 Journals (cost 11s. 6d. each) are available from the offices of the Society.

Changes of Address or Appointment

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters). Grade of Membership.

New address (in block letters). Old address.

New appointment.—Please give name and address of employer and position held.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 61 MAY 1957 NUMBER 557

Aeronautical Research in the Netherlands

by

Prof. Dr. Ir. H. J. VAN DER MAAS, F.R.Ae.S.

The one thousandth and twenty-third Lecture to be given before the Society, Aeronautical Research in the Netherlands, by Professor Dr. Ir. H. J. van der Maas, F.R.Ae.S., was given at the Institution of Mechanical Engineers, 1 Birdcage Walk, S.W.1, on 24th January 1957. Introducing the Lecturer, MR. E. T. JONES, C.B., O.B.E., M.Eng., F.R.Ae.S., President of the Society, said:—

They were fortunate in having as their lecturer that evening a very important man of aeronautics in the Netherlands. Professor Doctor van der Maas was not by any means a stranger to them. For one thing he was a Fellow of the Society and secondly, he had previously given a lecture before the Society. That was in 1929 and he thought it was appropriate that they should recall that meeting. In 1929 the Society organised an International Aeronautical Exhibition at Olympia and eminent speakers from France, the Netherlands, Sweden, Great Britain and Italy attended this exhibition and each gave a résumé of aeronautical progress in their respective countries. The speaker on that occasion from the Netherlands was their lecturer this evening. However, much had happened in aeronautics since 1929 and they were glad to welcome again Professor van der Maas, to bring them up-to-date in aeronautical research and equipment in the Netherlands.

Essentially Professor van der Maas was an engineer and in particular, an aeronautical engineer, although he believed that he graduated from the University of Delft as a naval architect. He started his career in aeronautics in 1923 as a scientific officer, as quite a lot of them had done, in flight research work when he joined the National Aeronautical Research Institute, better known as the N.L.L.—an abbreviation of its Dutch name, Nationaal Luchtvaartlaboratorium. He had held a commercial pilot's licence, as well as a military licence covering both sea- and landplanes. He did not know whether he still kept up his practice, but it was pretty good to have been qualified to fly aircraft of all three representative users.

Early in 1940 he was appointed Professor of Aeronautical Science at the Delft University and immediately after the war he was made Dean for one year of that University. In 1946 he was appointed President of the Aircraft Development Board in the Netherlands and in 1949, Chairman of the National Aeronautical Research Institute.

Professor van der Maas had been honoured twice, first with the Order of the Orange Nassau and, secondly, he was a Knight of the Order of the Netherlands Lion. He was also a founder member of the Advisory Group for Aeronautical Research and Development within NATO and he, personally, had had the privilege and honour of working very closely with him within that organisation for about six years. He thought he could say that Professor van der Maas was a great friend of many of them and a great admirer of the Society's work.

1. Introduction

It is a great honour to be invited to present a survey of the aeronautical research in the Netherlands to this distinguished audience and I wish to express my thanks to the Council of the Royal Aeronautical Society for giving me the opportunity to deliver this lecture. The more I appreciate it in view of the friendship between our two countries, between the Society and its Dutch counterpart and the personal friendship with so many present on this occasion.

It is my intention to give a survey of some of the work performed in the Netherlands in the post-war period and to describe briefly the main installations which are now available or under construction. I hope that I will be able to give you an impression of the scope and the nature of the aeronautical research activities in the Netherlands. These activities are being directed in the first place by the immediate needs of the industry and the aircraft operators; and in the second place by the desire to contribute to the general development of the art, thereby also supporting the exchange of results on an international basis, even more essential than before, considering the rapidly growing importance of aviation in its broadest sense.

Before entering into more technical matters it may be worthwhile to give very briefly an outline of the present organisation of aeronautical research and development in the Netherlands.

When at the end of the Second World War our Government considered the possibilities for rebuilding the national aircraft industry—which in the twenties and thirties had made a good name for itself in world aviation—it decided to embark upon a programme of government-assisted development and research. It therefore instituted the Netherlands Aircraft Development Board, which was made responsible for a programme of aircraft development together with the associated research; the funds made available for these purposes were also entrusted to the Board. A large percentage of the aeronautical research in the post-war period was done under contract to this Board, either in direct connection with the development of specific aircraft types, or as part of the more general programme which should lay the foundations for future developments.

Realising the large lag in our knowledge and experience, the first goal of the post-war activities was to try and catch up with the new developments in the field of aerodynamics, flight mechanics and structural research.

Part of the work which I hope to describe is directly concerned with these aspects and I would, therefore, beg you to consider this fact when I mention some work, which might appear to be neither original nor very important, but which can nevertheless be considered as an essential part of our activities.

In the development of actual aircraft the situation

FIGURE 1. Fokker F.27 Friendship air liner.

just mentioned has led to a not too ambitious programme, aimed in the beginning mainly at the development of training aircraft, in order to rebuild the potential for somewhat more advanced projects, like the Fokker F.27 Friendship air liner (Fig. 1).

After 10 years this "rebuilding stage" can be considered as more or less completed: therefore I appreciate being able to present a survey at this time.

The main part of the aeronautical research is concentrated in the National Aeronautical Research Institute (N.L.L.), at Amsterdam, so most attention will be given to the work of this Institute.

In addition, research is being done by the aircraft industry in the fields of production methods, new materials, development of structures, and so on. Moreover, some research work has been started by the Department of Aeronautical Engineering of the Technological University, Delft.

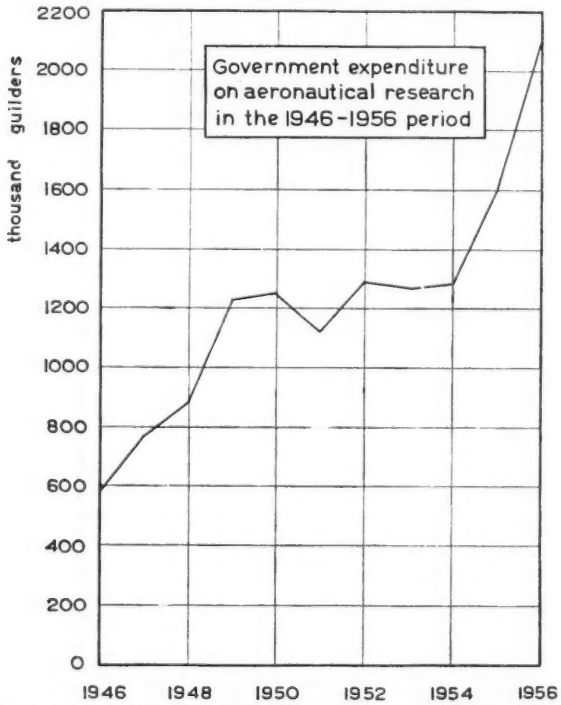


FIGURE 2. Government expenditure on aeronautical research in the 1946-1956 period.

Although the manpower available for aeronautical research and development has steadily increased from the early twenties onwards, it should be borne in mind that in a small country like the Netherlands the total effort could only be a modest one. As a rough impression of the magnitude of the post-war activities, Fig. 2 presents the yearly government expenditure on aeronautical research in the 1946-1956 period, while Fig. 3 shows the manpower in the Dutch aircraft industry and—for comparison—the strength of the personnel of the N.L.L. over the same period.

The total amount of money made available for the present expansion of the N.L.L. installations will run to about 22,500,000 guilders (£2,100,000).

2. National Aeronautical Research Institute

2.1. ORGANISATION

The National Aeronautical Research Institute—known by the abbreviation of its Dutch name "Nationaal Luchtvaartlaboratorium" as N.L.L.—originated from the Government Establishment for Aeronautical Research which was founded in 1918 under the direction of Dr. E. B. Wolff. In 1937 the organisation was changed from a purely governmental establishment into an institute, directed by a board which, besides a number of officials representing the various ministries concerned,

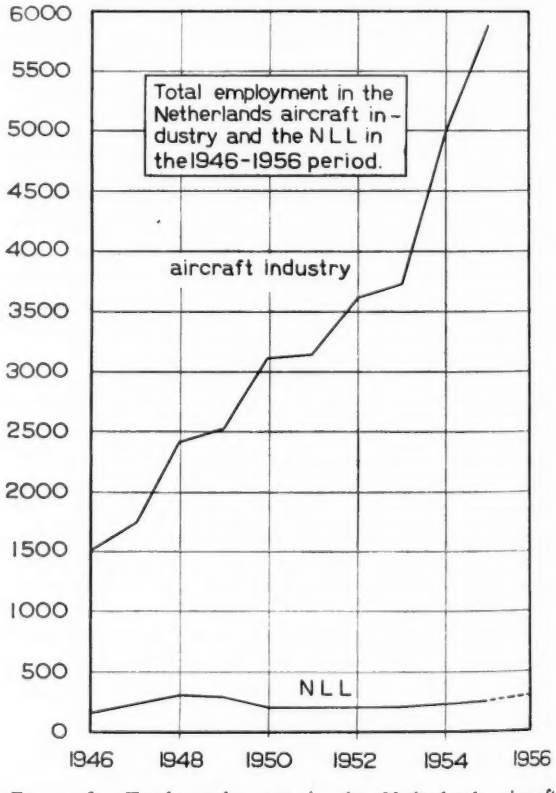


FIGURE 3. Total employment in the Netherlands aircraft industry and the N.L.L. in the 1946-1956 period.

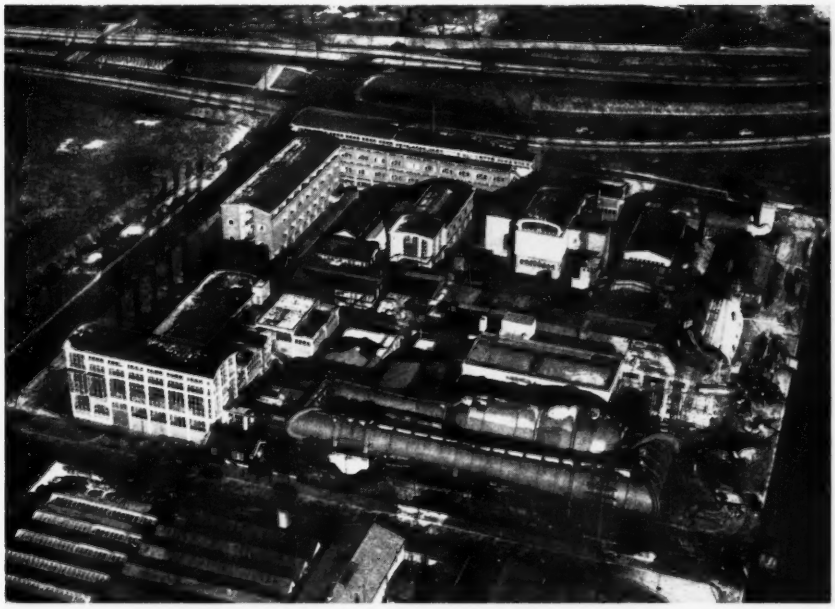


FIGURE 4. General view of the N.L.L.

includes representatives of the industry and the aircraft operators. This board is responsible to the Government.

The Institute is situated on the outskirts of Amsterdam and Fig. 4 gives a general impression of the arrangement of the present installations and those which are nearing completion. The personnel of the N.L.L. consists at present of about 65 university graduates, 105 other technical staff members, 65 workshop personnel and 65 administrative and internal services (approximately 300 in all).

2.2. AERODYNAMICS

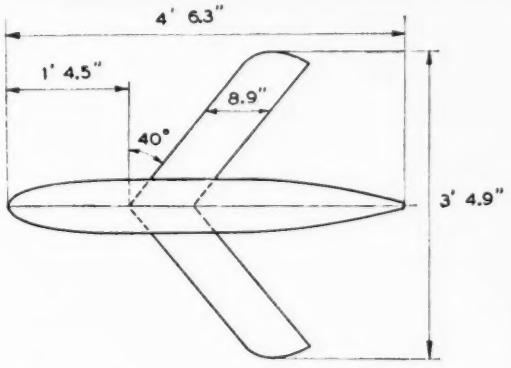
2.2.1. *Low speed wind tunnels*

The backbone of the aerodynamic laboratory of the N.L.L. for the past 15 years has consisted of two single-return-circuit wind tunnels for measurements in the low subsonic speed range (*see* Table I on page 298, tunnels 3 and 4).

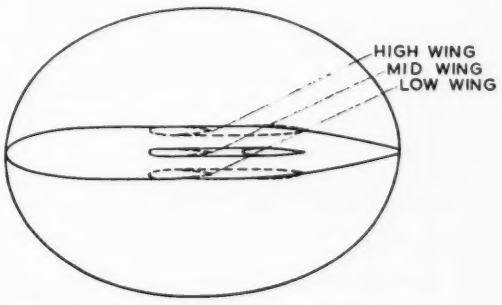
The *small low speed tunnel* has an open test section of 5 ft. × 5 ft., in which a maximum speed of 130 ft./sec. can be reached. The Reynolds number is rather low (maximum 600,000); the tunnel is only equipped with a mechanical three-component balance system of simple design. For these reasons this tunnel is mostly used for non-aeronautical tests (models of trains, cars, ships, buildings, and so on) and for calibration of instruments, although aeronautical research work has also been done in this tunnel.

Besides experiments on oscillating two-dimensional wings, to be described later in more detail, investigations on swept-back wings and on helicopter rotors have been performed during the past years. Part of the investigations on swept-back wings were related to downwash problems.[1]

A study of the influence of the wall on the flow around a *half-span model of a swept wing* has not yet been completed. A first impression of this effect has been obtained by adding a flat oval disc in the plane of symmetry of a 40 degrees swept wing model of aspect ratio 4·6 (Fig. 5). Tests have been made on the wing



TOP VIEW OF THE SWEPT-WING MODEL WITH FUSELAGE



SIDE VIEW OF THE MODEL WITH WALL

FIGURE 5. Model for wall interference tests.

TABLE I.

WIND TUNNELS OF THE N.L.L.

	WIND TUNNELS IN OPERATION				WIND TUNNEL UNDER CONSTRUCTION	WIND TUNNELS IN DESIGN	
	Low speed tunnel (*No.* 3)	*Small low speed tunnel* (*No.* 4)	*Small supersonic tunnel* (*No.* 7)	*Pilot tunnel* (*No.* 8)	*Transonic tunnel* (*No.* 9)	*Supersonic tunnels* (*No.* 10)	(*No.* 12)
Working section							
a Type	Closed[1]	Open	Closed	Closed	Transonic	Free jet	Free jet
b Size	Octagonal 7 ft. × 10 ft.	Square 5 ft. × 5 ft.	Square 1¼ in. × 1¼ in.	Rectangular 1·4 ft. × 1·8 ft.	Rectangular 5 ft. × 7 ft.	11—8 in. × 11 in.	4—3 ft. × 4 ft.
c Length	13 ft.	7 ft.	1¼ in.	3 ft.	28 ft.	1 ft.	5 ft.
Reynolds number, based on chord of wing with AR=5	2·2 × 10⁶	0·5 × 10⁶		0·8 × 10⁶			
Maximum speed or Mach number	260 ft./sec.	130 ft./sec.	$0{\cdot}5 \leqslant M \leqslant 6$	Max. *M*: 1·0 (empty working section)	Max. *M*: 1·3	$0{\cdot}5 \leqslant M \leqslant 6$	$1{\cdot}0 \leqslant M \leqslant 4$
Contraction Ratio	4·4 : 1	4·4 : 1	100 : 1	25 : 1	25 : 1	10 : 1	
Turbulence level	3 à 4 per cent	4 à 5 per cent		Low (8 screens)	Low (5 screens)		
Available power	600 h.p.	50 h.p.	25 h.p.	1,200 h.p.	20,000 h.p.	6,200 h.p.	
Pressure (working section)	1 ata	1 ata					
(settling chamber)			Variable 1—170 ata[2]	1 ata	Variable: 1/8—4 ata	Max. 40 ata	Max. 15 ata
Wind tunnel drive	Direct current motor[3]	Direct current motor[3]	Compressor[3]	2 fans with 2 squirrelcage-motors[4]	3 stage fan with 4 squirrelcage-motors[4]	Blow down	
Fan diameter	13·8 ft.	8·5 ft.		4 ft.	16 ft.		
Fan speed (r.p.m.)	900	780		3,600	610		
Speed control	Ward Leonard	Ward Leonard		Variable pitch and frequency	Variable pitch and frequency	Flexible nozzles	
Cooling or heating			Heater for high *M*	Air exchanger	Internal cooler	Internal heat-regenerators	
Balance system	Mechanical, 6 components	Mechanical, 3 components		Strain gauges	Strain gauges	Strain gauges	
Optical system			Schlieren-interferometer	Schlieren	Schlieren	Schlieren	
Date of construction	1940	1940	1948	1954	Expected to be ready for operation: 1957	Expected to be ready for operation: 1958	

(1) This tunnel can also be operated with open jet.
(2) High pressure air bottles (200 atm).
(3) Power from municipal supply.
(4) Power from N.L.L. turbo-electric plant.

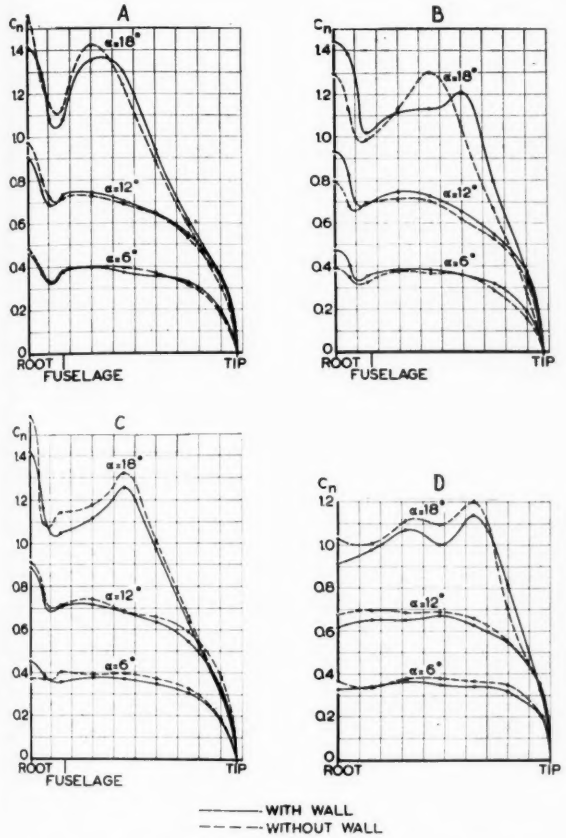
only and on fuselage-wing combinations in low-, mid- and high-wing configurations. The measurements included pressure distributions in a number of cross sections along the span and total pressure measurements in the boundary layers of the fuselage, the "wall" and the wing near the root.

From these measurements it appeared that the addition of the disc had an appreciable effect on the lift distribution of each of the wing-fuselage combinations (Fig. 6). Additional measurements with artificially thickened boundary layer along the "wall" revealed that these effects cannot be attributed to this boundary layer alone. Further studies of the interference effects between fuselage, wall and wing will be made to try and analyse these effects.

The field of *flow below and behind a helicopter* near the ground has been studied by means of wind tunnel smoke tests to get information about the best position for apparatus for crop spraying. For this investigation a simplified model of the fuselage and of the rotor has been used; the model had been placed above a floor mounted in the test section. Pictures of oil-smoke trails, as illustrated in Fig. 7, indicated that the streamlines below the rotor plane are bending outwards and are rolling up at some distance behind the rotor, so forming a kind of horse-shoe vortex line similar to that of a fixed wing. It appeared that the rolling up of the streamlines at the side of the retreating blade takes place at a greater distance behind the rotor than at the side of the advancing blade.

These effects become stronger with lower flight velocity and higher disc-loading of the helicopter.

The other *low speed tunnel*, with a maximum speed of 260 ft./sec. in the closed test section of 7 ft. × 10 ft., is used for *ad hoc* investigations for the aircraft industry and for basic research. At present it is equipped with a semi-automatic mechanical six-component balance system mounted on a turntable in a carriage above the



A. Mid wing configuration. *B.* Low wing configuration.
C. High wing configuration. *D.* Without fuselage.

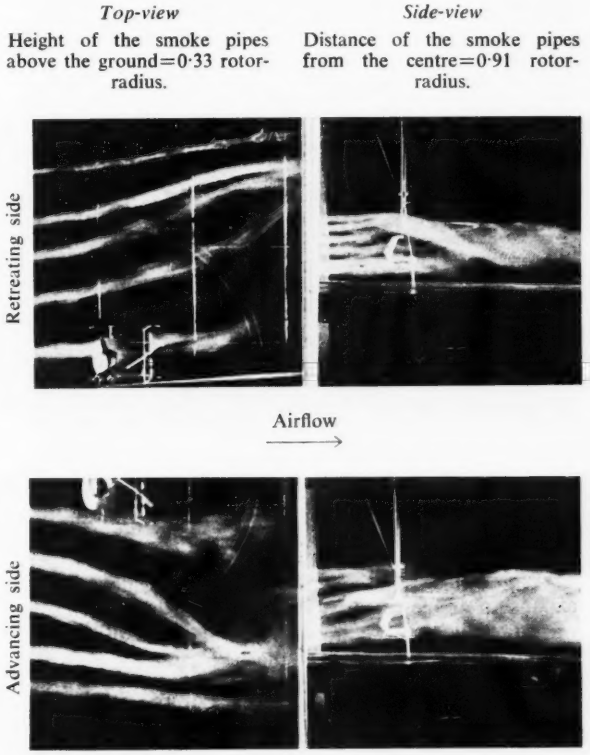
FIGURE 6. Normal force distribution along half-span of model with and without wall.

test section; a second carriage and turntable with sting-support for models with internal strain gauge balances is under construction.

During the past few years the greater part of the work performed in this tunnel was related to the Fokker Friendship. The remainder of the time has been devoted to measurements on models of other aircraft under development and to some basic research.

The programme of wind tunnel tests in connection with the *F.27 development* has been a very extensive one as altogether over 7,000 hours of tunnel operation have been spent on it; 2,600 on the complete model, and the remainder on components such as two-dimensional wing models with different flap configurations, fuselage nose (including rain-simulation for clear-view window testing), outer wing and tailplane for determining control effectiveness and hinge moments. It is not intended to describe the results of these tests, but one aspect, which will be investigated on a more general basis, may be worth mentioning.

In the configuration representing low speed flight under *asymmetric power* it appeared that the *adverse yawing* moment could be up to 80 per cent in excess



Thrust coefficient = 0·0024. Tip-speed ratio = 0·06.
Height of the rotor above the ground = 0·79 rotor radius.

FIGURE 7. Flow through helicopter rotor near the ground.

of the product of the asymmetric thrust and the distance to the plane of symmetry (Fig. 8). It appeared that the extra yawing moment increases with increasing C_L and results from a sidewash at the rear fuselage and vertical tail. These effects, as influenced by the aircraft configuration, will be studied in detail on a separate model both for high- and low-wing positions, in the course of this year.

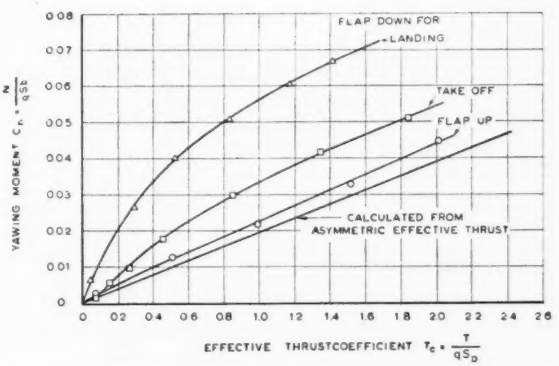


FIGURE 8. Comparison between one-engine inoperative yawing moment as determined from wind tunnel tests and calculations.

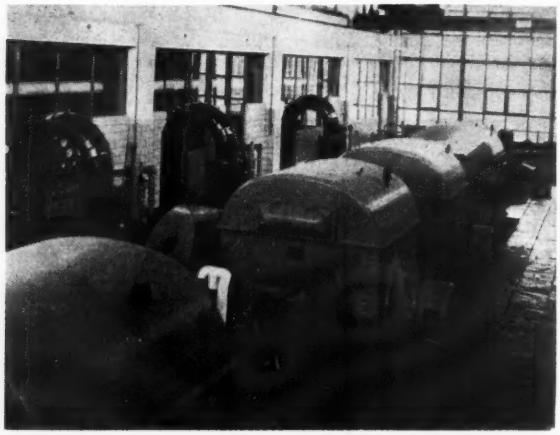


FIGURE 9. Turbo-generator units of N.L.L. power-plant.

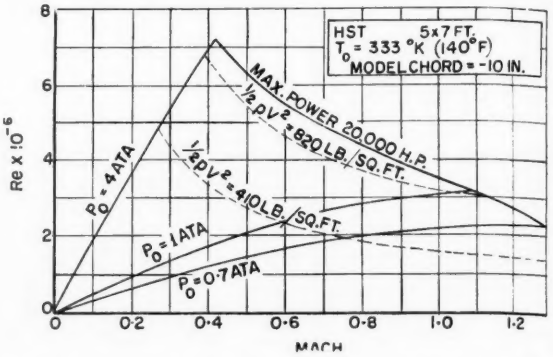


FIGURE 11. N.L.L. Transonic Tunnel (H.S.T.). Expected relation between Reynolds and Mach number.

2.2.2. *High speed wind tunnels*

2.2.2.1. *General*

When, in 1946, the first plans were made for the expansion of the research installations of the N.L.L., it was apparent that the emphasis should be put on wind tunnels for research in both the high subsonic and the supersonic speed range. Projects had been worked out to an advanced design stage when, around 1949, the work on these projects had to be temporarily slowed down and construction suspended. In 1953 work could be resumed. In the meantime the first information on transonic wind tunnels became available and it was decided to change the design of the large subsonic tunnel into a transonic one.

When the first planning of the new wind tunnels started, it was questionable whether the necessary power could be obtained from the municipal mains with sufficient flexibility and without undue restrictions, especially during peak hours. Steps were, therefore, taken to provide an independent power supply system, a solution feasible as the complete turbo-electric power systems of three war surplus escort vessels could be obtained at a relatively low price.

The present power station consists of 5 boilers, producing a total of 135 tons of steam per hour. This steam can be fed into 5 turbines, four of which are coupled to generators; one turbine is available for driving compressors. This set-up provides a large flexibility in the power supply. Fig. 9 gives a view of some of the turbine-generator sets.

2.2.2.2. *Large transonic tunnel*

A diagrammatic lay-out of the large transonic tunnel (HST) is shown in Fig. 10. This tunnel is a 5 ft. × 7 ft. variable-pressure tunnel, designed for a Mach number range of $M = 0 - 1{\cdot}3$. It was considered desirable to obtain as high a Reynolds number as possible and to be able to vary Reynolds and Mach numbers independently. Therefore, a variable pressure tunnel has been chosen.

Within the available power of 20,000 h.p., a Reynolds number based on the model chord of 2 to $3 \cdot 10^6$ can be reached in the transonic range when operating at atmospheric stagnation pressure, as shown in Fig. 11. In the range around $M = 1$, which will be one of the main regimes of the tunnel, the complications inherent to evacuation can, therefore, be avoided for many tests; only for Mach numbers above 1·1 has the tunnel to be evacuated. In the lower speed range, increasing the pressure makes it possible to achieve considerably higher Reynolds numbers than in the old low-speed tunnels.

Figure 11 also indicates that the maximum dynamic pressure in the tunnel—which determines the loads on models and model supports—will be around 850 lb./ft.²

The test section has longitudinally slotted upper and lower walls and a flexible nozzle upstream. The design and construction of this section has been entrusted to Swiss consulting engineers.* In this way the N.L.L. staff was relieved of one of the major problems in the design of this tunnel, which design in itself put a heavy burden on the aerodynamics staff, the more so as the research in direct connection with aircraft development could not be interrupted. Tests necessary for the design of the test section have been carried out at the Swiss Federal Aircraft Factory at Emmen, in a tunnel of similar design, but of smaller dimensions.

Around the test section which, because of the ventilated walls, had to be constructed with a separate pressure-carrying outer wall, ample room has been made available to house all observation and measuring equipment inside the pressure vessel. Provisions have been made for the installation of a schlieren and shadowgraph system, the optical axis of which can move in three directions as well as rotate around two axes in order to obtain as good a "three-dimensional" impression of the flow as possible. A television camera transmits the schlieren or shadow pictures to the control room and can also be used for direct observation of the model. In the slats of the upper and lower walls of the test section small photographic cameras will be mounted for additional observation purposes.

It will be seen from the sketch in Fig. 12 that the pressure vessel around the test section has been provided

*Dätwyler and Hausammann, Zürich.

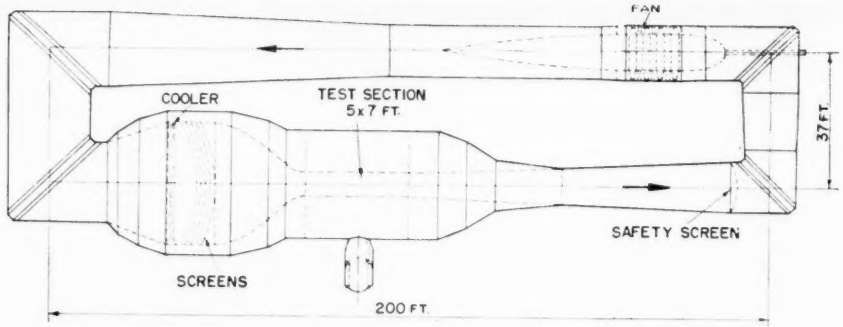


FIGURE 10. N.L.L. Transonic Tunnel (H.S.T.). Aerodynamic circuit layout.

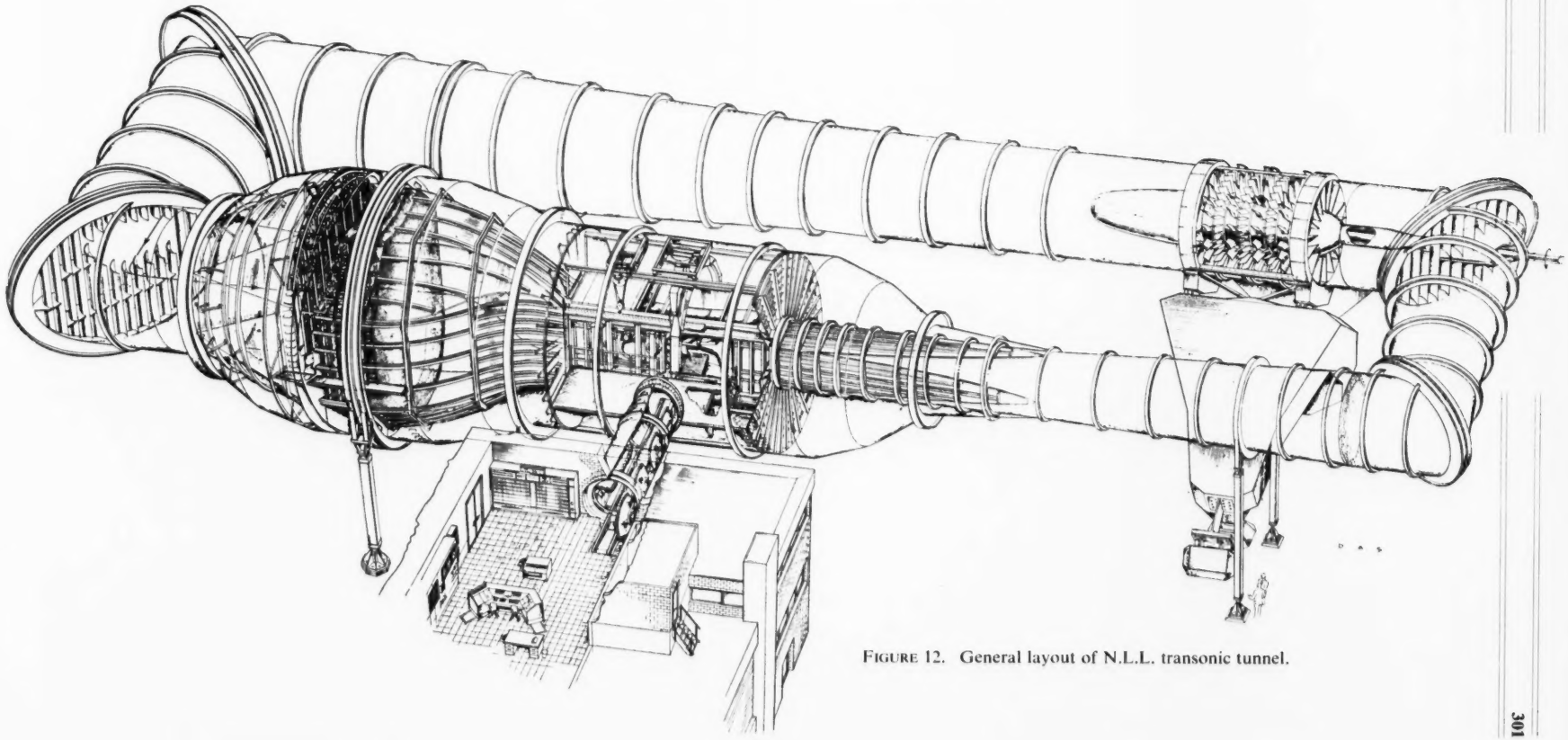


FIGURE 12. General layout of N.L.L. transonic tunnel.

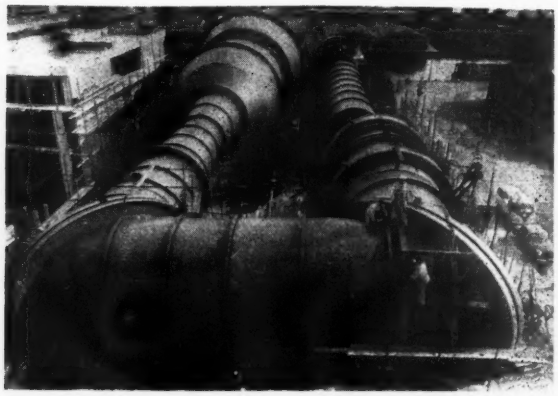


FIGURE 13. Transonic tunnel under construction.

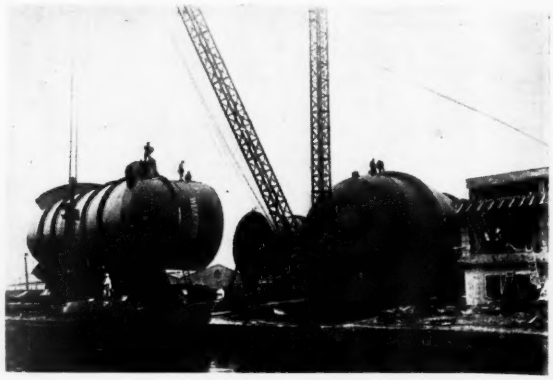


FIGURE 14. Placing of the last segment of the transonic tunnel.

with an air lock, allowing entry to the tunnel when the pressure inside this vessel is above, or below, atmospheric pressure, thus avoiding frequent pressure equalising. The structural design of the pressure vessel itself has been done at the N.L.L. under the supervision of van der Neut. Interesting details of these aspects have been described in Ref. 2.

The 20,000 h.p. tunnel drive consists of four coupled electric motors driving a four-stage compressor, designed for a maximum pressure ratio of 1·35. Although, due to the flexible power supply, the rotational speed of the fan is continuously variable, the fans have been constructed with variable pitch vanes. This complication was considered to be desirable, not only for obtaining a high efficiency of operation under all—widely varying—conditions, but also to permit quick acceleration and deceleration (even to zero) of the air flow. In this way costly time losses will be eliminated, which would result if the rotating masses of fan and motors themselves had to be changed in speed for each change in tunnel velocity; it takes 20 minutes to stop these masses from full speed.

Moreover, the variability of the fan pitch gives an additional regulating means to keep the tunnel speed at constant value for those cases in which the one-quarter per cent uncontrollable variation in the drive system r.p.m. should induce unacceptable air speed variations.

The tunnel is nearing completion as shown in Figs. 13 and 14, the second one picturing the recent closing of the tunnel circuit. It is hoped that the first test runs can be performed in the spring of 1957.

2.2.2.3. *Pilot tunnel*

In the original wind tunnel expansion programme a 1:5 scale model of the—then subsonic—large new wind tunnel was included. When the decision to change this into a transonic tunnel was taken, the model was in such an advanced stage of design that it was preferred to complete it according to the original plans. This tunnel, the layout of which is given in Fig. 15, was completed in 1955. It will be used for preliminary investigations of problems to be further elaborated in the large tunnel. Furthermore the test section will be equipped with ventilated walls in order to achieve with

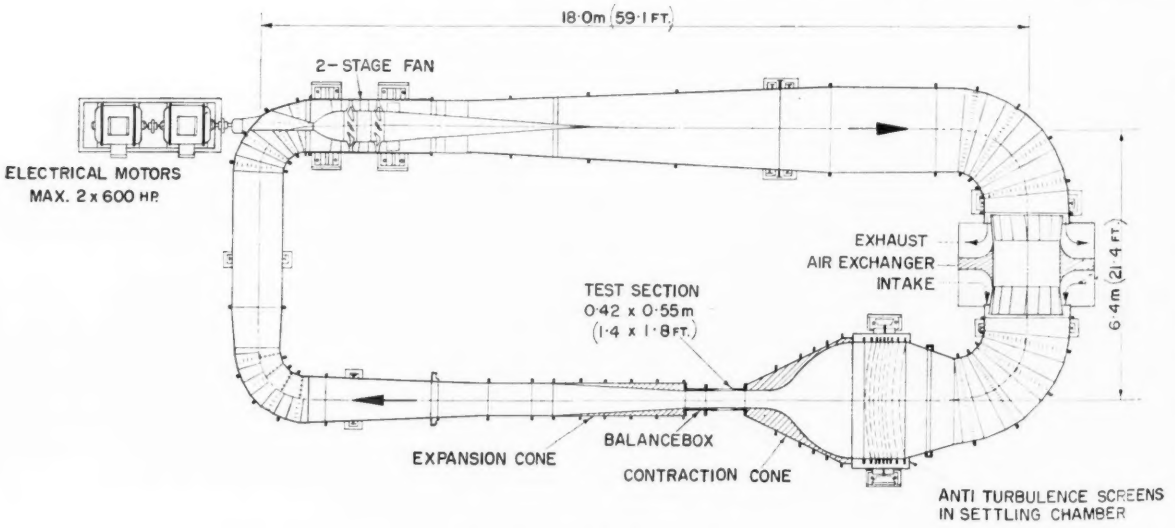


FIGURE 15. N.L.L pilot tunnel.

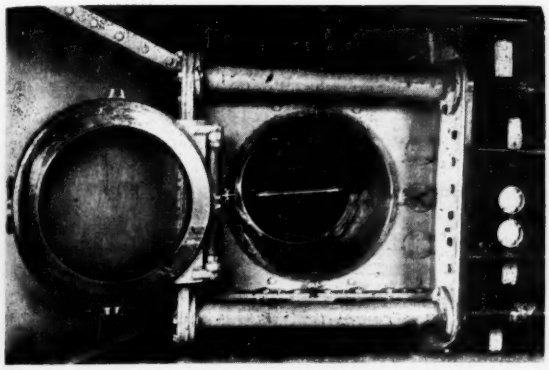


FIGURE 16. AGARD model C in test section of pilot tunnel.

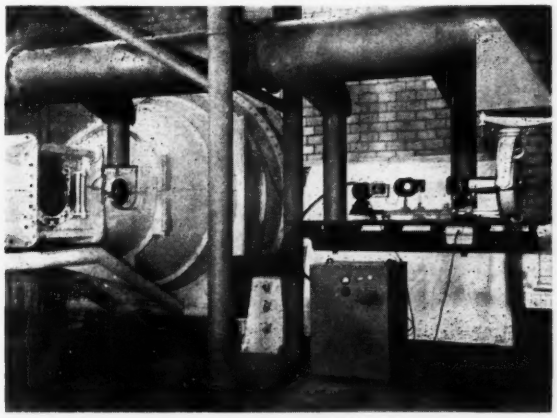


FIGURE 17. Schlieren apparatus of pilot tunnel.

the available 1,200 h.p. drive a test Mach number around 1·0.

The test section of the tunnel, which measures 1·4 ft. × 1·8 ft., is shown in Fig. 16 and Fig. 17 gives the general arrangement of the schlieren apparatus.

2.2.2.4. *Supersonic tunnels*

In 1947 a 1¼ in. × 1¼ in. supersonic wind tunnel (Fig. 18) was put into operation for preliminary investigations on a small tunnel of low operating costs.

The tunnel can be operated either continuously (by suction from the atmosphere via a dryer), or intermittently (blow-down system) with stagnation pressures up to 170 ata, stagnation temperatures up to 600°K. and a running time of about 50 seconds. Details of the tunnel and its instrumentation are given in Ref. 3.

This tunnel has been used first for investigations for a larger project as, for instance, the comparison of the efficiency of different types of diffusers, the development of nozzles (sharp corner at the throat and subsonic converging part), the effects of boundary layer suction along the tunnel wall and an investigation of the possibilities for measurements with half-models.

The diffuser research[4] resulted in the same optimum three-plate diffuser also developed in the United States.

In addition the tunnel has been used for basic research and for the development of instrumentation. Work has been done on shock wave-boundary layer interaction; Mach numbers up to 6 have been obtained (Fig. 19[5]); different tunnel configurations have been studied (half-tunnel, symmetrical tunnel, symmetrical nozzle and half-diffuser, and so on). Other examples are the development and testing of apparatus for measuring wall-temperatures and heat-transfer, and an experimental study of transonic test sections with transversal and longitudinal slots.

The most important result obtained in this 1¼ in. × 1¼ in. tunnel was the development of the Erdmann

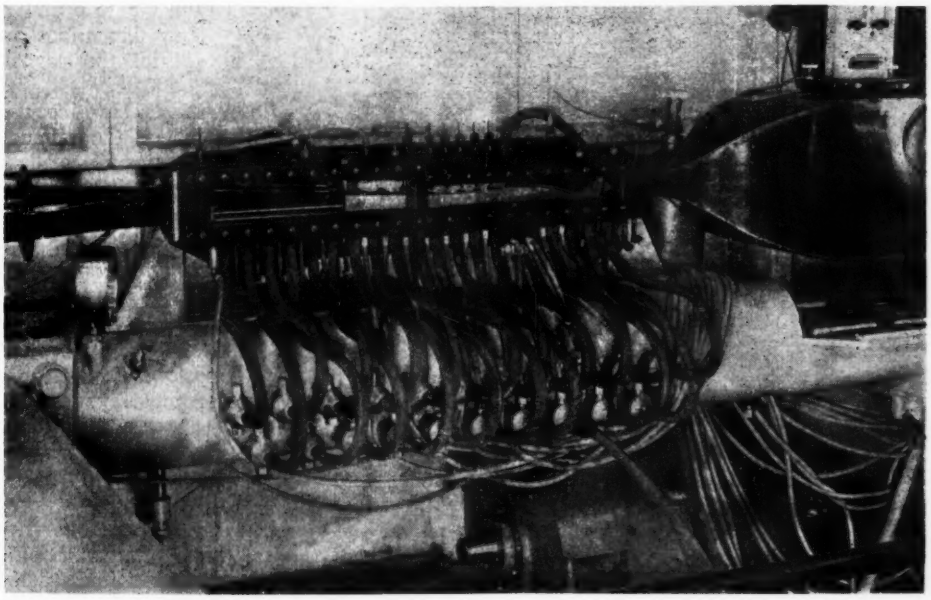


FIGURE 18. N.L.L. 1¼ in. × 1¼ in. supersonic wind tunnel (with suction along one of the walls).

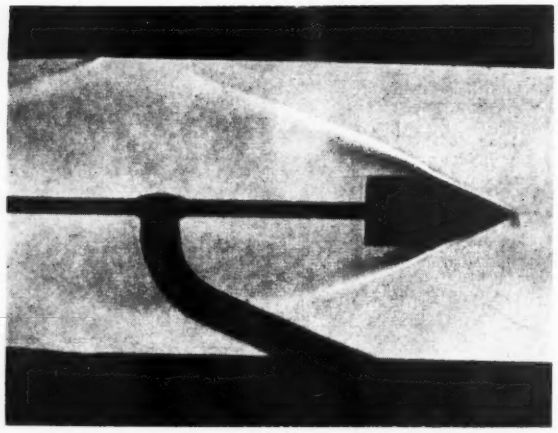
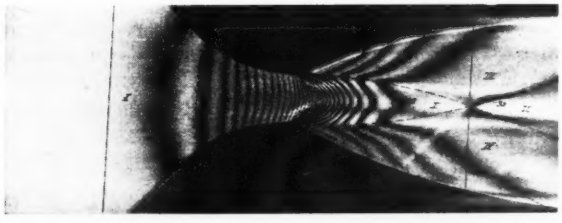
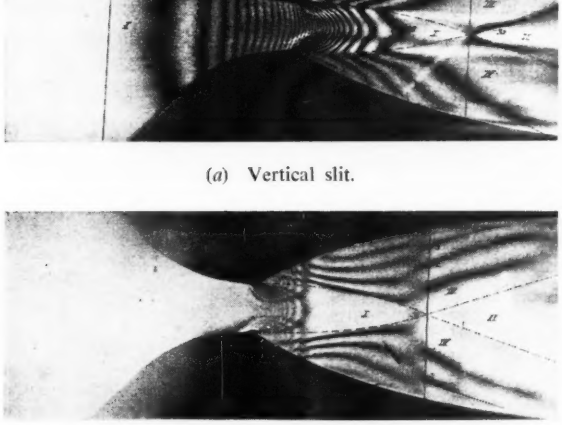


FIGURE 19. Flow around a cone cylinder model at $M = 6$.

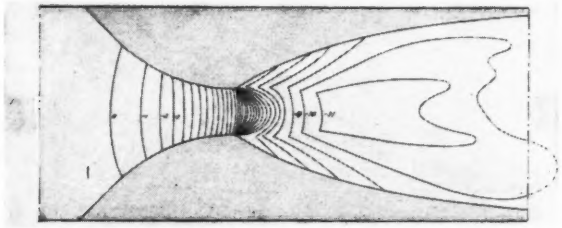
interferometer.[6] Every schlieren system can be changed into an interferometer of this type by using a very small, but strong, light source (slit of about 0·2 mm. width) and by replacing the knife edge by a mirrorplate, absorbing 90 to 98 per cent, with a clear (not absorbing) slit 0·01 to 0·1 mm. wide, depending on the geometry of the schlieren installation. The principle of the method is, in short, as follows. The light passing through the clear slit (situated where normally the knife edge is placed) has a uniform phase and is spread out over the whole plane of the flow picture. The light passing through the absorbing part of the mirrorplate gives a uniform illumination in the plane of the flow picture with only phase variations corresponding to the density distribution of the flow. The intensity of this light is reduced by absorption to that of the spread out light of uniform phase that passed through the clear slit. These combined pictures result in a clear black-white interference-line pattern, corresponding to differences of whole wave lengths in the optical path. Quantitative data can be drawn from such a picture.



(*a*) Vertical slit.



(*b*) Horizontal slit.



(*c*) Result derived from (*a*) and (*b*).

FIGURE 20. Results Erdmann Interferometer.

The flow field can be determined from two photographs, one with a horizontal and another with a vertical slit. This is illustrated in Fig. 20(*a*), (*b*) and (*c*).

When a schlieren system is available, the cost of the extra equipment is extremely low; the system is being further developed.

Together with the experimental research mentioned, theoretical studies have been performed in several fields. For instance the development of a simplified and partly numerical, exact characteristics-method for determining the shape of supersonic nozzles has been published.[7, 8, 9] In this method special attention has been given to the conditions at the throat.

A *new supersonic wind-tunnel project* has been set up. The project (Fig. 21) consists of two tunnels. The first one is a supersonic tunnel for development work, designed for $M = 1{\cdot}0$ to $4{\cdot}0$ and a Reynolds number based on model length, up to $R = 50 \times 10^6$. The dimensions of the test section are 4 ft. × 4 ft. up to $M = 1{\cdot}4$, changing to 3 ft. × 4 ft. at $M = 4$.

The dimensions of the test section of this tunnel have also been determined by the desire to use the same models and (if possible) instrumentation as for the 5 ft. × 7 ft. transonic tunnel.

The second-tunnel has been designed for Mach numbers from 0·5 to 6 and Reynolds numbers up to $R = 10^7$. The dimensions of the test section are 11—8 in. × 11 in., the stagnation temperature can be raised up to 500°K.

Both tunnels have been designed as intermittent blowdown tunnels, the running time of the big one being 35 seconds, that of the smaller one several minutes.

A schematic diagram of the tunnels and some interesting details are given in Fig. 21, together with some technical data.

2.2.3. *Flutter*

Following the fruitful investigations by Koning and von Baumhauer,[10] around 1922 on a phenomenon which is now well known as flutter, but which at that time was completely new and embarrassing, investigations of flutter problems have been resumed in later years. Flutter is still one of the items of the N.L.L. research programme to which continuous effort is being devoted.

Extensive calculations have been made of *critical flutter speeds for a number of wing and aileron configurations* in which stiffness and inertia parameters have

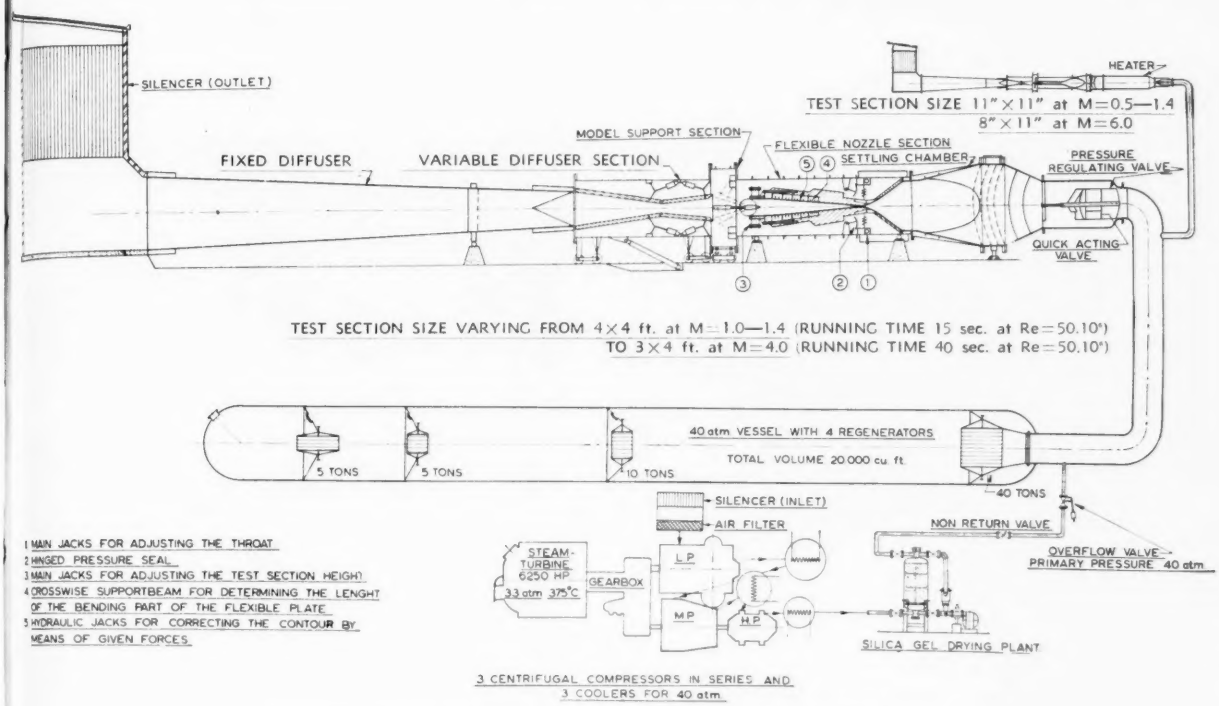

SILENCER (OUTLET)
HEATER
TEST SECTION SIZE 11"×11" at M=0.5—1.4
8"×11" at M=6.0
MODEL SUPPORT SECTION
FLEXIBLE NOZZLE SECTION
SETTLING CHAMBER
FIXED DIFFUSER
VARIABLE DIFFUSER SECTION
PRESSURE REGULATING VALVE
QUICK ACTING VALVE
TEST SECTION SIZE VARYING FROM 4×4 ft. at M=1.0—1.4 (RUNNING TIME 15 sec. at Re=50.10⁶)
TO 3×4 ft. at M=4.0 (RUNNING TIME 40 sec. at Re=50.10⁶)
40 atm VESSEL WITH 4 REGENERATORS
TOTAL VOLUME 20.000 cu. ft.
5 TONS
5 TONS
10 TONS
40 TONS
SILENCER (INLET)
AIR FILTER
NON RETURN VALVE
OVERFLOW VALVE PRIMARY PRESSURE 40 atm
STEAM-TURBINE 6250 HP 33 atm 375°C
GEARBOX
L.P.
M.P.
H.P.
SILICA GEL DRYING PLANT
1 MAIN JACKS FOR ADJUSTING THE THROAT
2 HINGED PRESSURE SEAL
3 MAIN JACKS FOR ADJUSTING THE TEST SECTION HEIGHT
4 CROSSWISE SUPPORTBEAM FOR DETERMINING THE LENGHT OF THE BENDING PART OF THE FLEXIBLE PLATE
5 HYDRAULIC JACKS FOR CORRECTING THE CONTOUR BY MEANS OF GIVEN FORCES
3 CENTRIFUGAL COMPRESSORS IN SERIES AND 3 COOLERS FOR 40 atm

FIGURE 21. General lay-out of projected N.L.L. supersonic wind tunnel plant.

been varied systematically.[11, 12, 13] Furthermore, the complexity of modern aircraft necessitated the development of *flutter calculations* in which *many degrees of freedom* can be taken into account.[14]

The aerodynamic derivatives used in these calculations have been based on the theories of Küssner and Theodorsen.[15, 16]

It was felt desirable to have an *experimental check on* these theoretical *values of the aerodynamic derivatives*. To this end an extensive wind tunnel programme was initiated a few years ago. Until now only oscillating wing-flap systems in two-dimensional incompressible flow have been tested. The model consisted of a rigid wing, free to rotate around a spanwise axis, the position of which could be varied; a hinged flap with a chord of 40 per cent of the total chord was attached to the wing. The "forcing through a spring" method has been used and the response to a harmonic excitation measured. Amplitude and phase of the wing and flap motion with regard to the exciter have been determined. In this way force, pitching moment and hinge moment due to translation, or rotation of the wing, or due to flap deflection, could be evaluated.

In general, it was found that the experimental wing derivatives agreed to within 10 or 15 per cent of the theoretical values. For the flap derivatives (*i.e.* hinge moments and derivatives due to flap deflection) the discrepancy was, however, much more important.[17–21] For example, in Fig. 22 the results for the hinge moment coefficient n_δ due to flap deflection have been plotted as a function of the reduced frequency $\omega = \nu l/V$, where ν = frequency, l = semi-chord and V = air speed. For the three flap configurations shown, the results are mutually not very different. Compared with theory the experimental results all show a considerably lower value of the aerodynamic derivatives. Furthermore, the reduction ratios are not the same for the in-phase components (R) and the out-of-phase components (I).

In these tests the reduced frequency has been varied by varying the air speed and keeping the frequency of excitation constant. Hence, the Reynolds number varied between 100,000 and 800,000. During the first experiments difficulties have been encountered due to chordwise movements of the boundary layer transition point with varying effective angle of attack during the oscillation. This gave rise to additional forces leading to larger deviations from the theoretical results. With the help of a smoke method, the motion of the transition points during the oscillations has been made visible. For a laminar boundary layer the smoke—emanating from the surface in the vicinity of the quarter-chord point—forms a clear thread, while for a turbulent boundary layer the smoke obtains a very irregular form at its outer side. This is seen in the photographs of Fig. 23. In the first, the boundary layer at the upper side is laminar, which corresponds to a negative angle of incidence. In the next, the angle of incidence is less negative and it has a positive value in the last two photographs. With increasing angle of incidence the boundary layer at the upper side of the wing is seen to become more and more turbulent. From these photographs could be concluded a time lag between the real position

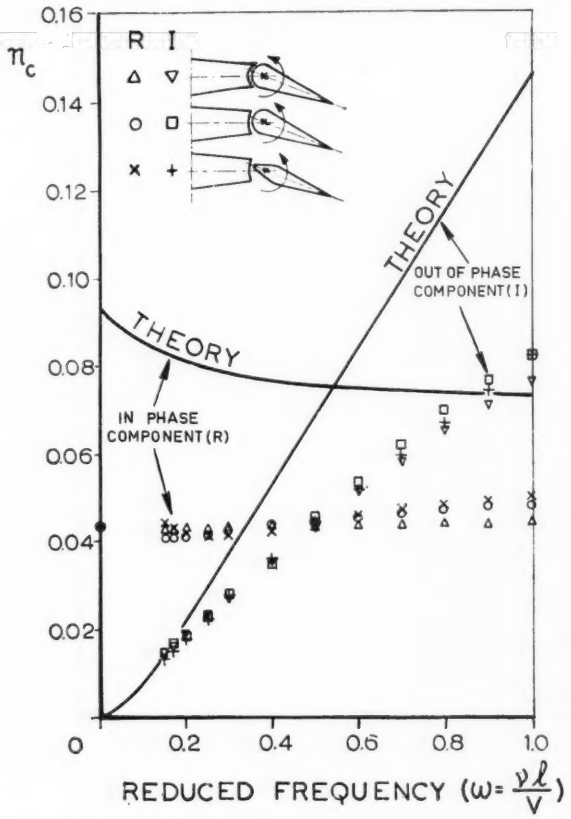


FIGURE 22. Comparison between theoretical and experimental values of the hinge moment coefficient n_c for oscillating wing with flap.

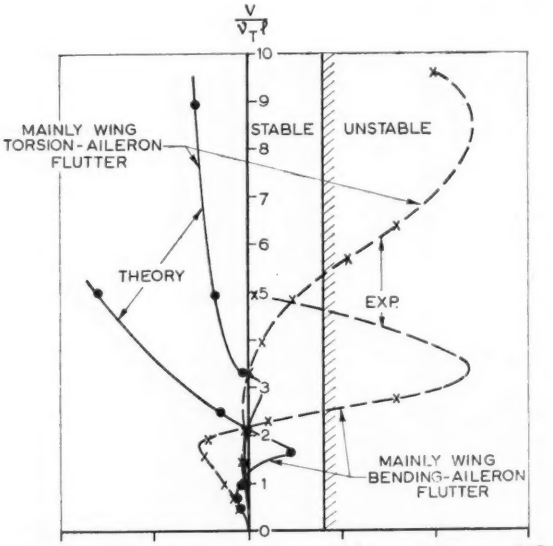


FIGURE 24. Comparison between flutter boundaries as calculated from experimental and theoretical aerodynamic derivatives.

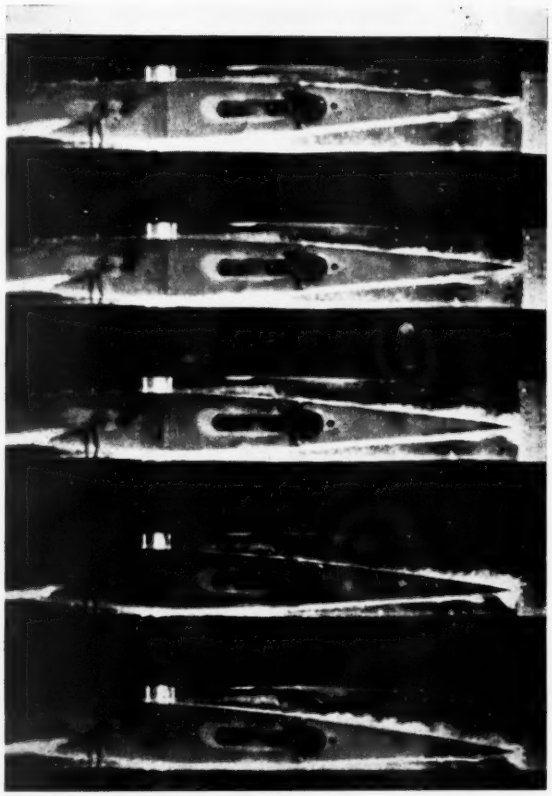


FIGURE 23. Boundary layer of oscillating aerofoil at varying angles of attack.

of the transition point and the one according to quasi-steady theory.

In the frequency range explored, up to 10 *Hz*, the phase lag is roughly proportional to the frequency; consequently the time lag turns out to be independent of the frequency.

The difficulties mentioned could be overcome by fixing the transition point by means of turbulence wires near the leading edge of the wing. As in real flight conditions the transition point generally is situated well forward, it may be expected that the value obtained from the measurements with turbulent boundary layer will give a better approximation of full-scale conditions.

The effect on the calculated flutter speed of using the experimental values instead of the theoretical ones has been investigated. For some cases this effect appears to be quite important, as shown in Fig. 24, referring to a case of bending-torsion-aileron flutter. The inertia axis of the aileron lies a small distance aft of the hinge axis. Along the vertical axis the flutter speed V, made dimensionless by aid of the uncoupled natural frequency in torsion ν_T and the semi-chord l has been plotted, while the structural damping g—defined as the phase angle between force and deflection—has been plotted along the horizontal axis. Assuming a value of 0·04 for the structural damping, it is seen that the system would be stable according to a

calculation using the theoretical aerodynamic forces, but would appear to be unstable if experimental aerodynamic forces are being used in the calculation.

The experimental and theoretical results differ both in magnitude and in phase; so the question may arise which of the two is predominant. Since at altitude the magnitude of the aerodynamic forces is reduced without change in phase, a calculation has been made for an altitude of 15,000 ft. using theoretical aerodynamic forces. This has been done to investigate whether the reduction of the experimental forces in comparison with the theoretical results is responsible for this change, or whether the difference in phase is also essential. This calculation also did not show any instability, from which it may be concluded that the phase differences between the theoretical and the experimental forces indeed are essential. More cases however, have to be considered before it is known whether the somewhat alarming result shown in Fig. 24 is representative or exceptional.

It may also be questioned whether aerodynamic forces measured at a Reynolds number of 800,000 can be considered to be acceptable approximations for the aerodynamic forces on full-size aeroplanes. This point will be investigated further by additional wind tunnel measurements at a Reynolds number of about 5,000,000. It is known, however, that aileron tab systems, which would be free from flutter according to calculations using theoretical aerodynamic forces, may in reality still show some form of mild flutter. This can only be due to a difference between theoretical and experimental aerodynamic forces. Therefore, it is of great importance to know more about the real aerodynamic actions, not only at low speeds but still more at higher speeds.

The *theoretical investigations* have, at a later stage, also been extended to include *compressibility effects*. In Refs. 22 and 23 a method has been presented for the calculation of aerodynamic forces and moments acting on a two-dimensional aerofoil with flap, in compressible flow. This method leads to an analytical solution in terms of Mathieu-functions of the boundary value problem for the wave equation. The solution has been obtained by using the concept of the acceleration potential. The complete solution can be separated into a regular part, giving the correct normal acceleration at the aerofoil, and a singular part which takes into account the pressure singularity at the leading edge. Numerical results have been acquired for a series of Mach numbers up to 0·8 and reduced frequencies up to 1·0, both for the plain wing and the wing with flap.[24, 25, 26] These results have been applied to systematic flutter calculations for a cantilever wing,[27, 28] from which it appeared that bending-torsion wing flutter is, in general, little affected by compressibility up to $M = 0{\cdot}7$, while the wing-aileron flutter speed is increased in many cases if the Mach number exceeds 0·5.

The introduction of *three-dimensional effects into unsteady aerodynamic theory* has given rise to a number of rather elaborate approximate theories.[29, 30] For the circular and elliptical plan forms in subsonic flow, it is in principle possible to develop a solution by using appropriate orthogonal co-ordinates. In order to arrive

Flat circular plate, $\alpha = 1$

	C_L	C_M
Kinner	1·8174	0·9358
Krienes and Schade	1·7984	0·9318
Kochin	1·7908	0·9378
Küssner	1·6976	0·8488
Multhopp	1·7880	0·9372
N.L.L.	1·7902	0·9326

Cambered circular wing, $\alpha = \frac{x}{l_0}$

(l_0 = semi-chord in middle section)

	C_L	C_M
Kinner	0·9350	−0·4376
Krienes and Schade	0·9436	−0·4382
Küssner	0·8488	−0·4434
N.L.L.	0·9326	−0·4388

FIGURE 25. Values of lift and moment coefficient of circular wing according to various theories.

at the solution of the unsteady problem a method has been developed at the N.L.L. which, as a first step, has been applied to the circular wing in *steady* incompressible flow. The results of this method can be used to check the more approximate theories. With this new method, in which the concept of the acceleration potential is being used,[31] the Kutta condition is satisfied along the entire trailing edge while in the other approximations this condition is only satisfied in a limited number of points. Finally, an integral equation in only one variable has been obtained which can be solved by aid of Fourier expansion. This expansion converges very rapidly; no differences being found in the values of C_L and C_M, when calculated to four decimal places, if the integral equation was solved by retaining 2, 4, 6 or 8 terms in the Fourier expansion. Results are shown in Fig. 25, where C_L and C_M are given for a flat circular plate at a certain angle of incidence α and for a cambered wing of which the local angle of incidence increases linearly with the streamwise co-ordinate. With the exception of Küssner's results, there is a good agreement between the different theories.

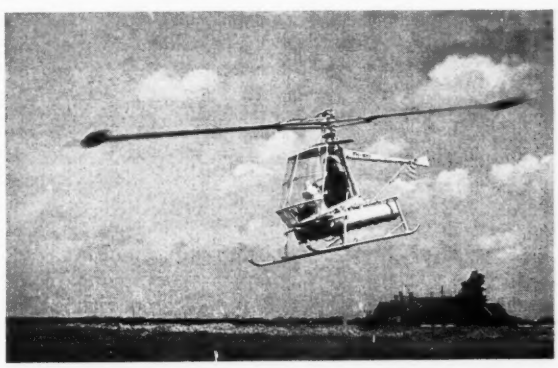


FIGURE 26. Ram-jet powered Kolibrie helicopter.

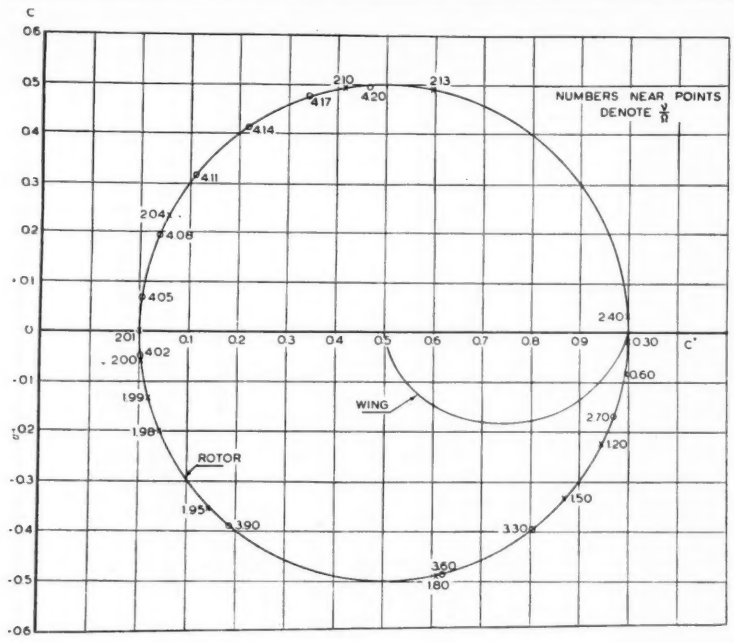


FIGURE 27. The circulation function C for a two-bladed helicopter rotor in symmetric oscillation, compared with the orthodox C-function for a wing.

During the development of the Kolibrie helicopter—a small ram-jet powered helicopter illustrated in Fig. 26—difficulties have been encountered during the ground testing phase. The *dynamic behaviour of the rotor* has therefore been investigated by aid of a model. It appeared that unstable oscillations, as well as flutter, could occur, but only if the model blades were rotating in still air near the zero-lift condition. In all cases the flutter frequency was almost equal to a multiple of the rotor angular velocity. Since the rotor was two-bladed it is clear that if this multiple is even (2 or 4), the oscillations of the two blades are in phase, while for an odd multiple they are in anti-phase. This means that at any point of the circumference, each blade performs the same motion. Spanwise wake vortices are being accumulated during the transient phase of the motion. Once the steady condition is reached, no new vortices are being generated and the blade oscillates in the standing vortex pattern along the rotor disc. Hence, it may be concluded that this wake vortex pattern is an essential condition for the occurrence of this type of flutter, to be called *wake flutter*. Since the configuration in the vortex sheet is quite different from that of a fixed wing, it is not surprising that flutter calculations according to the orthodox aerodynamic theory failed to show instability.

A suitable theory has been developed[32, 33, 34] which considers the flow on a cylindrical surface of which the axis coincides with the rotor axis. Unrolling this cylindrical surface a train of aerofoils is obtained; the corresponding two-dimensional flow has been calculated. According to this theory the usual formulae for the derivatives of a single aerofoil may be used, provided that the circulation function C is modified. This circulation function C denotes the reduction of the aerodynamic force for an oscillating translating aerofoil compared with the quasi-steady value. This reduction is caused by the spanwise wake vortices. In the case of no flow through the rotor disc, this function assumes values in the complex plane lying on a circle with its centre at the point 0·5 and a radius equal to 0·5 (Fig. 27). It is seen in this figure that an important difference exists between the orthodox C-function and the present one. The numbers along the circle denote values of ν/Ω, where ν is the frequency of the oscillation and Ω the angular rotor speed. The reduced frequency is equal to $\omega = \nu l/(\Omega r)$ while for the case shown in this figure $l/r = 1/15$. The figure refers to symmetric oscillations.

It is seen that for values of ν/Ω, which are almost equal to even integers, the C-function can become zero, in contrast to a normal wing where the circulation factor C is always larger than 0·50. This has important consequences for the flutter behaviour of the rotor.[35] For $C=0$ the damping on flapping or bending oscillations vanishes altogether and one-degree-of-freedom bending flutter becomes a possibility.

A typical diagram showing flutter regions is given in Fig. 28. The quantities ν_B and ν_T denote the natural frequencies of the non-rotating blade in flapping and torsion, respectively. From this diagram the flutter speed can be derived. If the rotor speed is increased, the relevant point P will travel along a straight line

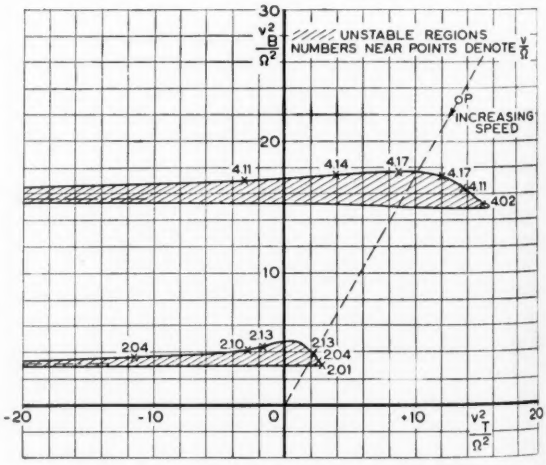


FIGURE 28. Flutter diagram for two-bladed rotor without forward speed.

towards the origin. The point, where this line intersects one of the flutter boundaries, determines the flutter speed. It can be shown that, to prevent wake flutter, the blade must be very carefully mass-balanced, including the aerodynamic inertias. In the case represented in Fig. 28, the structural mass had been balanced, not so the aerodynamic inertia; it was the latter unbalance which caused the unstable regions.

The reduced damping found in this investigation for helicopter blades may also turn out to be an important factor when considering blade vibrations caused by the varying downwash along the circumference of the rotor disc. This, however, may be a subject for future research.

2.2.4. *Helicopter problems*

Investigations have been made of the flow through helicopter rotors, both in general aspects[36] and in connection with the development of the Kolibrie helicopter which has a *self-adjusting rotor blade system* which greatly enhances the stability characteristics of the rotor.

A major contribution has also been made towards the development of the ram-jet engines which power the Kolibrie. Measurements on a static test bench have later been complemented by tests on a whirling arm (Fig. 29).

Air flow at the helicopter blade tips has been studied in connection with the problems of *contamination* of the ram-jet engine, as in some conditions part of the exhaust gases of a ram-jet may be swallowed by the other engine.[37] This contamination occurs in the whirling arm pit and affects the results of the thrust and consumption tests of the ram-jet engines. Measurement of the inlet air temperature in the ram-jet gives an indication of the magnitude of the contamination and serves as a basis for corrections.

2.2.5. *Boundary layer theory*

In the field of boundary layer research, investigations have been performed concerning the *three-dimensional laminar boundary layer*. The final purpose of this investigation is the calculation of the boundary layer of a swept wing with a known pressure distribution. A method has been developed which is based upon the

FIGURE 29. Whirling arm pit for helicopter ram-jet.

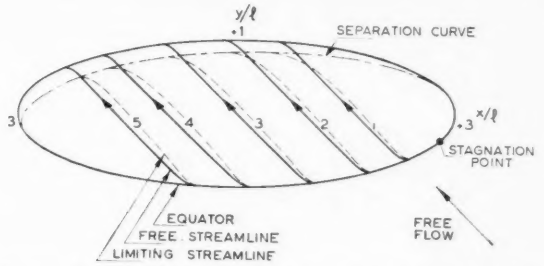


FIGURE 30. Potential and boundary layer flow around a three-dimensional ellipsoid.

complete momentum equations for the boundary layer in the directions parallel and perpendicular to the local potential flow[38]. The boundary layer profiles in these two directions are chosen; then the momentum equations lead to two partial differential equations for the thicknesses of these two profiles. These can be solved by numerical integration.

The calculations are, however, very elaborate and therefore it was tried to simplify the method. This appeared to be possible[39] if it is assumed that the cross flow in the boundary layer relative to the local direction of the flow outside the boundary layer is not too large. Then in the momentum equation in flow direction, the cross flow is neglected and the boundary layer thickness can be calculated by solving a total differential equation. In this equation, the three-dimensional character of the potential flow is, of course, taken into account. The results for the boundary layer in flow direction are now substituted into the momentum equation for the cross flow, which then can also be solved.

The method has been applied to a three-axial ellipsoid, with axis ratios 3: 1: 0·15. The plane through the two longest axes is called equator plane. In the case considered the angle of incidence of this plane was zero, the undisturbed flow making an angle of 45° with the two long axes. Fig. 30 shows the results for the potential (free) streamlines and the corresponding limiting streamlines; the latter denoting the streamlines at an infinitely small distance from the body. It is seen that all streamlines follow the equator for a certain distance and then turn away sharply. The limiting streamlines make a still sharper turn due to the fact that they are subject to the same pressure gradient, while the centrifugal force is less. The line of separation has also been indicated. This is the envelope of the limiting streamlines, which has been calculated with the aid of the approximate criterion that the shear stress in the direction of the local potential flow vanishes.

The *stability of the laminar boundary* layer with a pressure gradient in two-dimensional, incompressible flow has been the subject of another investigation[40]. The method of solution of the differential equation for the perturbation stream function is a different one, compared with that applied by other investigators. By making use of the asymptotic character of the velocity profile, it is possible to solve the "inviscid" perturbation equation by aid of one integration, starting from infinity and integrating to the wall. This avoids the

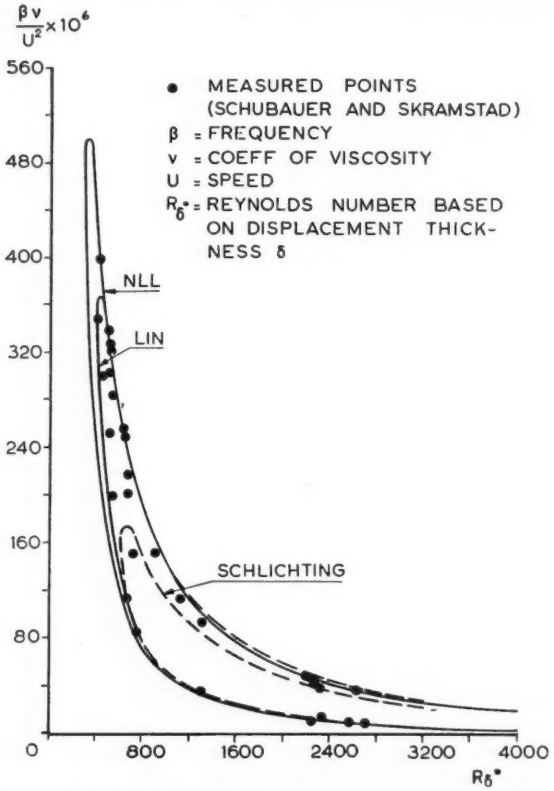


FIGURE 31. Instability diagram for laminar boundary layer on a flat plate according to different theories.

difficulty of calculating two solutions which have to satisfy a certain relation at the outer side of the boundary layer. It may be expected that the results obtained by the N.L.L. method will be more accurate. In Fig. 31 the frequencies β, which become unstable in a certain range of the Reynolds number R_δ^*, based upon the displacement thickness δ^* are shown for the case of a flat plate. The ordinate has been made dimensionless by means of the coefficient of kinematic viscosity ν and the undisturbed air speed U. Results from measurements by Schubauer and Skramstad[41] have also been included. According to the N.L.L. results the minimum value of the Reynolds number for which instability may arise is 320, while the value given by Tollmien[42] and also by Lin[43] is 420 and that by Schlichting[44] 575.

2.2.6. *Gust loads*

In the field of gust loads a series of investigations has been performed during the past decade. The first investigations were concerned with a *rigid* aeroplane for which the loads due to a single gust have been calculated[45, 46, 47]. Pitching of the whole aeroplane was taken into account, which required the determination of the aerodynamic forces at the tail. A number of parameters, such as wing loading, position of the centre of gravity and gradient distance of the gust were varied. As a result alleviation factors were obtained for a great number of cases and this led to a proposal for improved airworthiness requirements concerning gust loads[48].

Lately, some calculations on gust loads for *elastic* aeroplanes have been made.

A system of automatic gust load alleviation, based upon the introduction of a mechanical coupling between wing bending and aileron deflection in such a way that for an upward gust both ailerons are deflected upward, has been studied.[49] It was concluded that such a system permits, theoretically, a reduction of gust loads of the order of 10-20 per cent. The magnitude of the mechanical coupling is limited by the requirement that the aerodynamic damping for oscillations may not become too small.

2.2.7. *Measurement of stability derivatives*

The method of measuring the response of a system which is excited by aid of springs—used for checking flutter derivatives—has also been applied to the measurement of stability derivatives. Such measurements have been performed at low speeds on the AGARD D-model, which consists of a wing of aspect ratio 5, the plan form of which is rectangular for the middle part and trapezoidal for the outer parts. The results for the damping in pitch—if the pitching axis lies a distance of 9 semi-chords aft of the quarter chord line—are shown in Fig. 32. It is seen that the results are independent of the reduced frequency and that they are in good agreement with those obtained from quasi-steady theory. The last conclusion, however, only holds at low speeds.

Although no experiments have been performed in the high subsonic region, it follows from a theoretical investigation[50], that at Mach numbers of 0·7 or higher, the damping in pitch is not correctly obtained from quasi-steady theory. It is then necessary to take into account the proper unsteady effects, such as the finite speed of propagation of disturbances and the influence of the spanwise wake vortices. According to the theory of oscillating aerofoils, the damping also depends on the reduced frequency; but attention has been focused in Fig. 33 on the limit of the damping coefficient C_{m_q} if the frequency approaches zero. This figure shows this limiting value as a function of the position of the pitching axis. The distance of this axis aft of the quarter-chord axis is denoted by $\bar{z}l$. The figure refers to a rectangular wing of aspect ratio 6·5 at Mach number $M=0{\cdot}9$. The differences between quasi-steady and unsteady results increase with increasing aspect ratio and increasing subsonic Mach number.

This investigation also showed that in a certain range of forward positions of the pitching axis the damping coefficient C_{m_q} may become positive if either the aspect ratio is larger than 6·5, or the Mach number larger than 0·9. This denotes unstable motion, related to the well-known phenomenon of flutter with one degree of freedom.

2.3. FLIGHT MECHANICS

The flight mechanics department of the N.L.L. is concerned with both theoretical work on aircraft performance, stability and control and with flight test

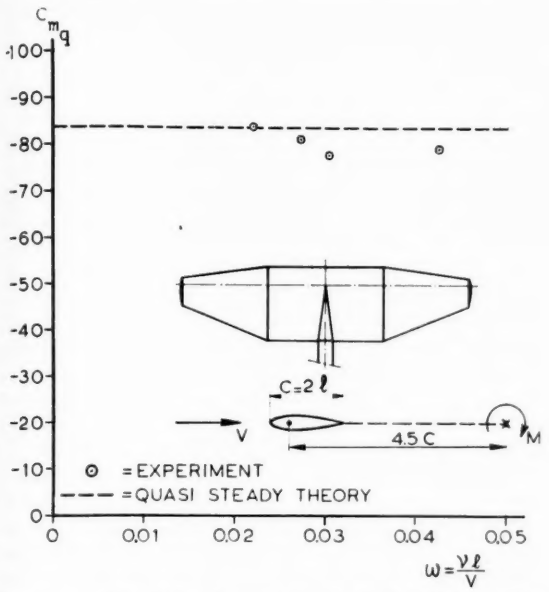


FIGURE 32. Comparison between experimental and theoretical values of C_{m_q} at low speed.

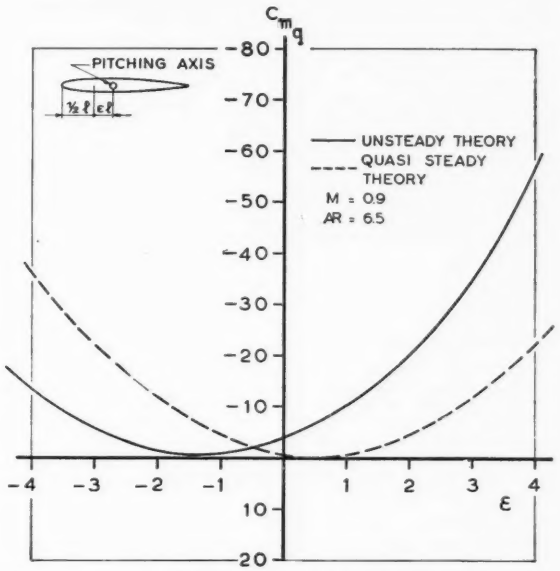


FIGURE 33. Damping moment in pitch according to quasi-steady and unsteady aerodynamic theory.

research and instrumentation problems. This department is also involved in the flight testing of prototype aircraft.

During the past years the theoretical work has mainly been related to flight test techniques.

Moreover, some investigations about separate subjects have been performed, among them studies on tailless aircraft[51], longitudinal stability problems[52, 53] and helicopter flight characteristics[54].

Besides the normal equipment necessary for flight tests with different types of aircraft, a small twin-engined Siebel transport aircraft serves as a flying laboratory. This fully "calibrated" aircraft is being used for flight test research and also for the development of new flight test techniques.

2.3.1. *Flight test research*

In the past few years *the measurement of performance in non-steady flight* has become a practical proposition, mainly due to the diligent efforts of the French CEV at Bretigny[55]. The method is based on the determination of the magnitude of the total aerodynamic force (defined as the sum of lift, drag and propulsive force) and its direction relative to the flight path.

Magnitude and direction can be measured relative to the aeroplane axes by a normal accelerometer and pendulum inclinometer respectively or alternatively, by two accelerometers placed at right angles to one another. The necessary conversion to the direction of the flight path requires the measurement of the angle of attack.

The success of the method depends entirely on the accuracy of the instrumentation, so particular care had to be taken in the selection of the instruments. The pendulum inclinometer and the normal accelerometer used by the N.L.L. are both photographically-recording instruments. In addition use was made of a longitudinal accelerometer, the sensing element of which was obtained in the U.S.A.*; the electric servo indication system was developed at the N.L.L. Accuracy and linearity of this instrument are both within 0·1 per cent of the full range of $\pm 0{\cdot}5g$. The angle of attack indicator, developed at the N.L.L., is a vane-type instrument with step-up gear and electric synchro indicator.

These instruments have been used in non-steady performance tests with the Siebel aircraft. The tests have been performed with both engines delivering climbing power, in accelerated horizontal flight as well as in accelerated flight at constant attitude.

The results of four climb tests, each lasting less than one minute, are shown in Fig. 34; the standard deviation of the measured rate of climb is 15 ft./min. The results of these tests have been checked against results obtained in steady flight and found to be in good agreement.

It has been found possible to obtain the aeroplane lift-drag polar with both propellers feathered, in a few minutes flying time with an altitude loss of about 3000 ft.; the accuracy of the so obtained drag coefficient is $\pm 0{\cdot}001$ (Fig. 35).

Between the two World Wars, fairly extensive and fundamental studies on longitudinal and lateral stability and control characteristics have been made and flight test techniques have been developed for the determination of aircraft flight characteristics in *steady flight*[56]. In addition to these techniques, the growing trends towards automatically controlled and artificially stabilised aircraft had made desirable a more detailed knowledge of the *dynamic characteristics* of an aeroplane. Studies have, consequently, been made of the

*Donner Scientific Instruments, Berkeley, U.S.A.

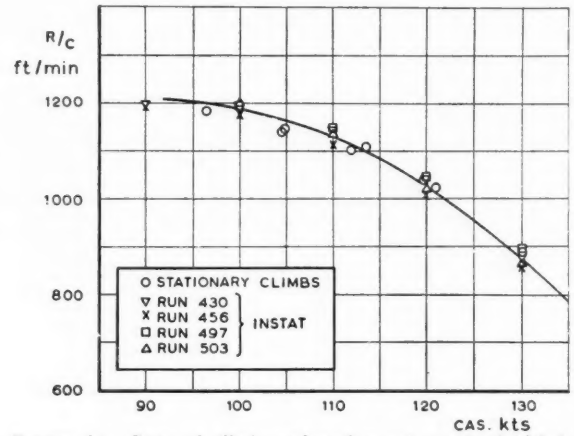


FIGURE 34. Rate of climb against forward speed of Siebel laboratory aircraft as measured in steady and unsteady flight.

test methods to be used for determining the transfer functions of an aircraft in flight. These test techniques, which have been developed in particular at Cornell Aeronautical Laboratory, can be divided into two groups, frequency response measurements and transient response measurements.

For some introductory tests in this field the N.L.L. selected the *transient response method*, because of the available equipment and the economy in flight time required. These tests have also been made with the Siebel laboratory aircraft. To facilitate comparison of the results with data obtained by calculations based on wind tunnel tests, the measurements were made with both propellers feathered.

The response of the aircraft to suddenly applied elevator deflections, was measured according to a so-called stick force step technique. To this end the aircraft was brought into steady flight at a chosen air speed, the stick force, however, not being trimmed out. By releasing the stick, a sudden but smooth elevator deflection could be obtained. Other techniques making use of mechanical stops at the controls were considered to be less favourable because of "bouncing" effects due to elasticity of the control circuit. Continuous records have been made of elevator deflection, pitching velocity and normal acceleration.

The evaluation of these records was done by means of the Fourier transform method, giving amplitude ratio and phase angle of output (*e.g.* pitching velocity q) relative to input (elevator deflection δ_e) as a function of frequency. An example of these curves is given in Fig. 36, which shows the frequency characteristics of the pitching velocity due to elevator deflection. A calculated curve based on results of model tests in the wind tunnel and full scale tests in steady flight has been added to the picture. The points in the figure correspond to three different test runs; it is seen that the scatter of these points is reasonably low.

Stability parameters were derived from the curves faired through the measured points by means of a least squares procedure and acceptable results were obtained.

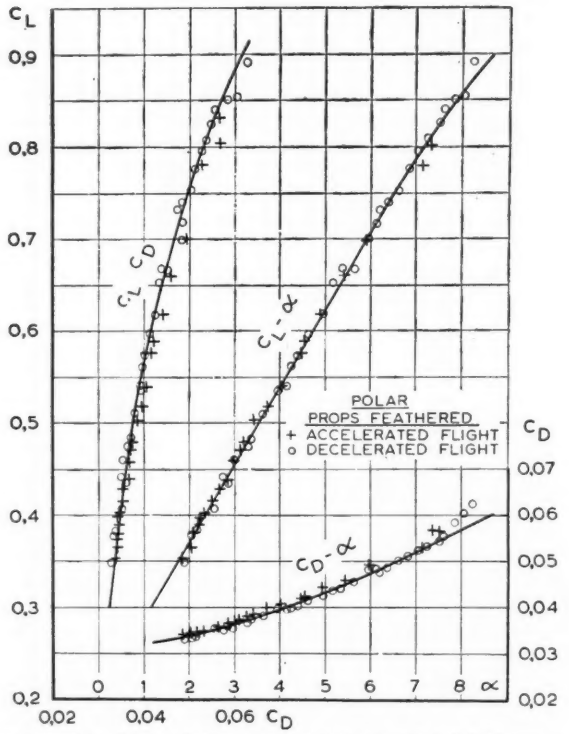


FIGURE 35. Lift and drag characteristics for Siebel laboratory aircraft as measured in unsteady flight.

2.3.2. *Ad hoc research related to prototype testing*

During the flight testing of prototype aircraft some particular problems have arisen which called for the development of additional equipment and test techniques. A few examples of this kind, which might be of interest, will be described.

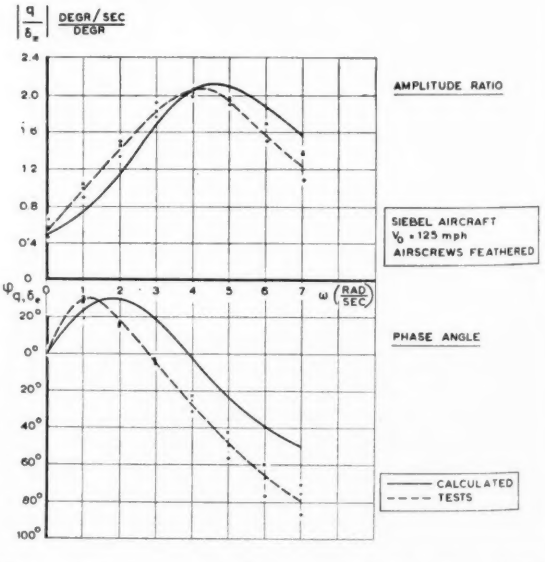


FIGURE 36. Comparison between calculated and measured frequency response curves for Siebel laboratory aircraft.

FIGURE 37. Pressure set transducers inside Fokker S.14 wing.

To obtain information on the forces and moments acting on the Fokker S.14 "Machtrainer" wing at transonic speeds, special equipment has been developed for *measuring the pressure distribution* in flight at a representative *wing section*[57, 58]. Pressure transducers of the potentiometer type were mounted inside the wing and connected to 49 equally spaced orifices in the wing section contour (Fig. 37). The electrical outputs of these transducers were scanned by a rotating commutator with two channels, one for the upper and one for the lower surface. The pressure patterns were scanned at a rate of five per second and recorded by an oscillograph.

The variables being lift coefficient and Mach number, the pressure distribution had to be determined in about 50 flight conditions; so a total of a few thousand pressure differences had to be measured.

Obtaining a simple data reduction method has therefore been one of the principal aims. All pressure transducers were adjusted in such a way that their calibrations did not differ more than two per cent from a standard calibration line. The sequence of scanning was such that the recording showed a geometric similarity with the desired graphs of the pressure coefficient against chord location. Corrections for supply voltage variations and for the difference between the static pressure of the undisturbed flow and the pressure in the wing interior (which was used as reference pressure for the transducers) and division of the measured pressure by the dynamic pressure, were made mainly by photographic procedures. In this way the final data could be made available shortly after the tests had been completed.

Figure 38 shows two original recordings of the pressure distribution, together with the final graphs. The upper and lower curves correspond to pressures at the upper and lower surfaces. The location of the shock wave at the upper surface of the wing—indicated by a large pressure rise—can easily be seen from the final graph.

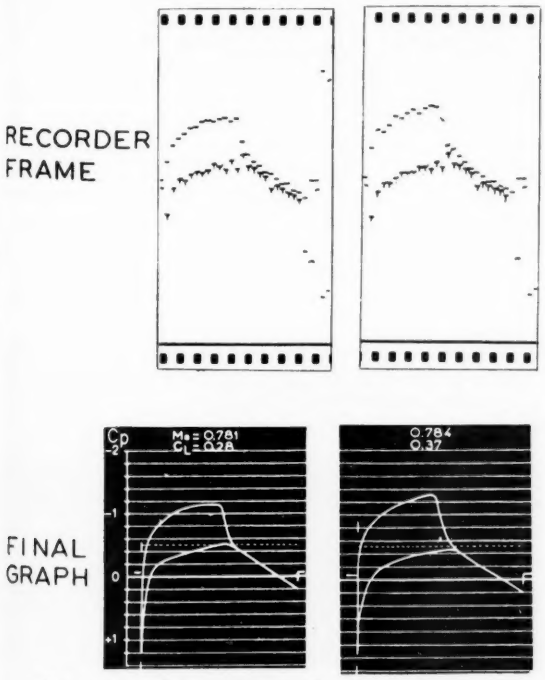


FIGURE 38. Wing pressure distribution measurements.

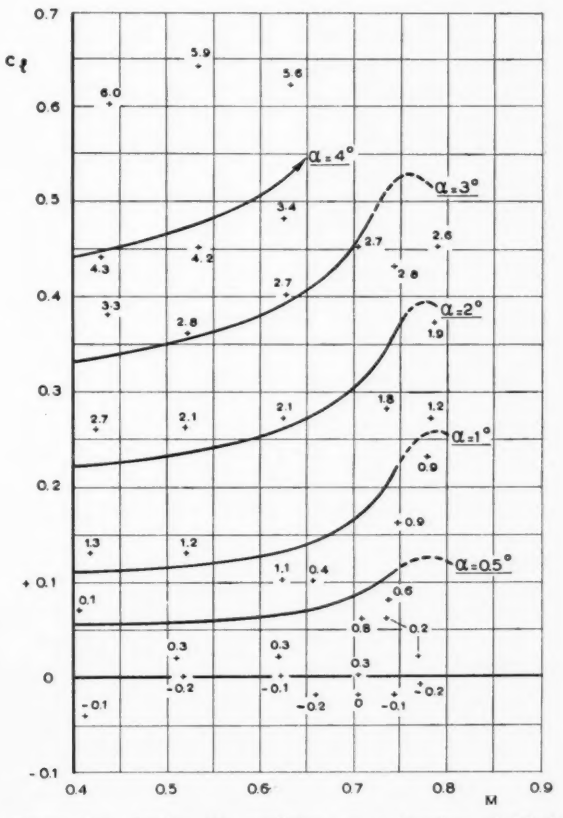


FIGURE 39. Section lift coefficient as a function of Mach number and effective angle of attack.

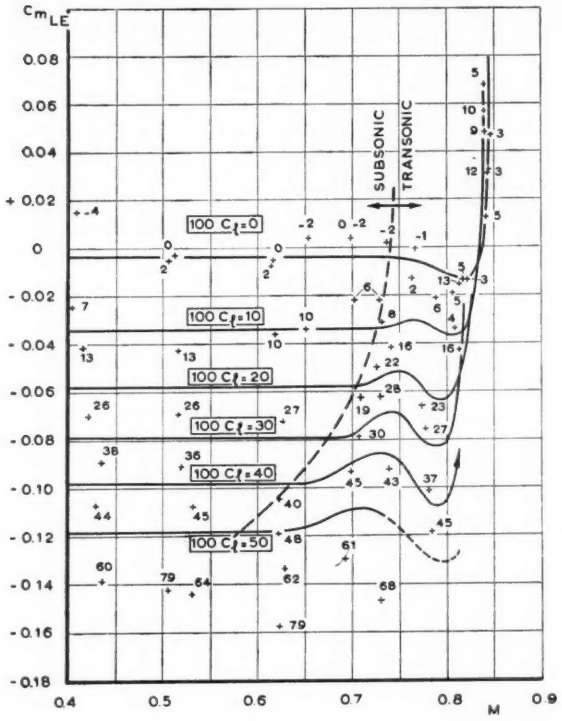


FIGURE 40. Pitching moment coefficient as a function of Mach number and lift coefficient.

The lift coefficients, obtained by integration of the pressure curves, have been plotted as a function of Mach number and effective angle of attack in Fig. 39. Each point in this graph has been provided with a figure indicating the angle of attack; curves for constant angles of attack have been faired in.

A similar graph (Fig. 40) for the pitching moment coefficient of the wing section could be derived from the pressure patterns. The figure shows that this coefficient tends to positive (tail heavy) values at high Mach numbers.

The equipment described has also been used for the estimation of the *pressure distribution on the cockpit hood* of the same aircraft at transonic speeds[59].

Tail loads in steady flight and in manoeuvres can be estimated with reasonable accuracy. For a *buffeting tailplane*, however an accurate prediction of the magnitude and frequency of the loads is practically impossible. Therefore experimental determination of the buffeting loads at transonic speeds is necessary.

To obtain information on these loads acting on the horizontal tailplane on the Fokker "Machtrainer" deflections of the tail have been measured in the transonic speed region[60].

A film camera was mounted in the fin of the aircraft and markers on both stabiliser tips were filmed by way of a mirror assembly fixed to the camera. A reference marker fixed to the camera was also recorded on the film by means of a collimator. Fig. 41 shows the principle of the equipment.

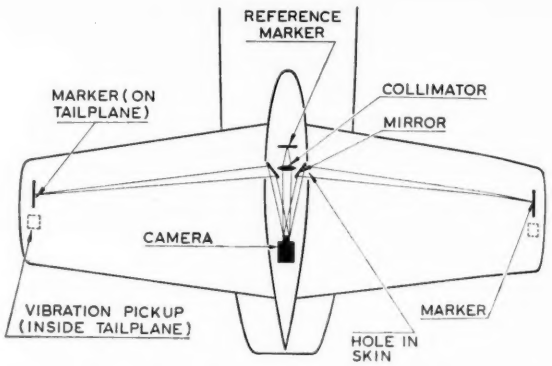


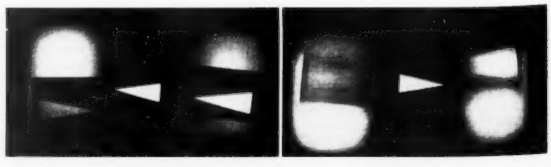
FIGURE 41. Principles of tailplane vibration measuring equipment.

Good results have been obtained with this method for steady, or slowly changing, tailplane deflections. A slightly different technique has been applied to tail buffeting: the camera speed chosen was so low, that the shutter was open for more than one period of the vibration. From the film pictures the amplitude of the vibration could then be measured directly.

To determine the frequency, piezo-electric acceleration transducers had been mounted in the stabiliser tips and their output fed into a continuous-trace recorder. Some care had to be taken with the interpretation of these recordings, as the acceleration transducers are also sensitive to angular accelerations of the aircraft around its longitudinal and lateral axes, and to torsional vibrations of the rear part of the fuselage. In most cases however, it was possible to distinguish frequencies of the tailplane bending vibrations from those of other vibrations. As an example Fig. 42 gives two records, one of which was made of a steady deflection of the tail; the second shows the vibrating tail.

The equipment described was used in flight tests during which pull-up manoeuvres were executed at different (high) Mach numbers. The results of these tests are given in Fig. 43, in which the stabiliser tip amplitude is given as a function of Mach number and aeroplane load factor. It is seen that an increase in both Mach number and load factor makes the buffeting more severe. No buffeting occurs within the line indicated as "buffeting boundary," corresponding to zero amplitude.

The knowledge of amplitude and frequency of the vibration served as useful information for the study of the problem of structural fatigue of the horizontal tailplane.



Film frame, static deflection. Film frame during vibration (long exposure).

FIGURE 42. Records of tail deflection measurements.

Three series of tests have been conducted to ensure that *canopy release* of the Machtrainer in emergency cases by means of the aerodynamic forces only, was absolutely safe:

(*a*) tests in the wind tunnel of the N.L.L. with a model constructed according to the dynamic similarity rules,

(*b*) tests with a full scale Machtrainer in the jet of the open wind tunnel of the A. & A.E.E. at Boscombe Down,

(*c*) tests in free flight during which the hood jettison was recorded from two escorting aircraft equipped with cameras, one of which was of the high speed type (1,000 frames/sec.). Fig. 44 shows a picture from these records.

A comparison of the results obtained during these investigations is presented in Fig. 45. The picture shows the trajectories of the rear point of the hood as derived from the wind tunnel tests and as measured in actual flight. It appears that the three trajectories agree reasonably well.

For the Fokker Friendship aircraft equipped with two Rolls-Royce Dart propeller-turbines, the *surface temperatures* of the structure had to be measured at a large number of points (about 100) in and around the engine nacelles. It was decided to apply resistance thermometers instead of the more generally used thermocouples. The resistance type of thermometer has several advantages: the indicators are more robust, no cold-junction is required, small-diameter high-resistance leads can be used to reduce the influence of the length of the connecting wires on the measurements and sensing elements of different types can be used in conjunction with one type of indicator by the addition of resistances to the circuit.

Special resistance sensing elements have been developed (Fig. 46), consisting of a flat Pertinax core on which enamelled nickel wire is wound. The elements are glued on the structure by a special substance, which provides a good joint and a reasonable protection against kerosine, especially when muffled.

The elements have a measuring range of −50 to +200 degrees C. Several hundreds have been made, the calibration of which differs less than three degrees from a common calibration curve. Some sensing

FIGURE 44. Hood jettisoning in flight.

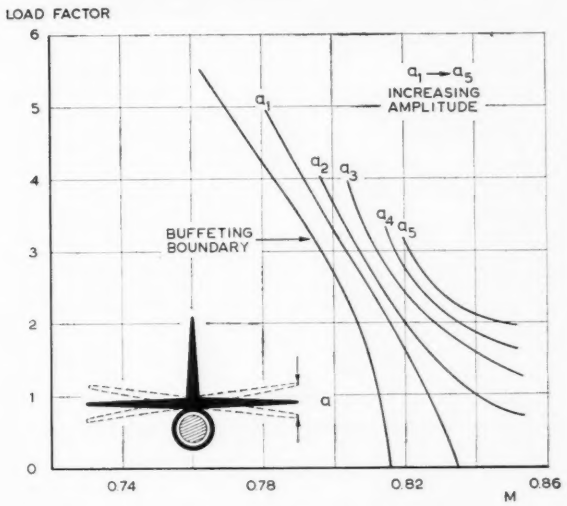


FIGURE 43. Relation between stabiliser tip amplitude, Mach number and load factor.

elements at less accessible spots in the structure of the Fokker Friendship were mounted during the construction of the aircraft and after two years no signs of deterioration have been detected.

In order to be able to record a large number of temperatures during the same flight, a six-channel scanning system has been built, in which each channel consecutively connects 12 elements to one pointer instrument.

2.4. STRUCTURES AND MATERIALS

2.4.1. *Static loads*

The structures and materials laboratories of the N.L.L. are fairly well equipped for conventional mechanical testing of structural components and materials. For this purpose a number of static and fatigue testing machines, impact machines, etc., are available, of which may be mentioned a 150 ton Avery compression testing machine, mainly used for testing stiffened panels.

Recording strain measuring equipment for up to 100 resistance strain gauges is available, and recording equipment for 200 gauges is being built for strain measurements on the new transonic wind tunnel.

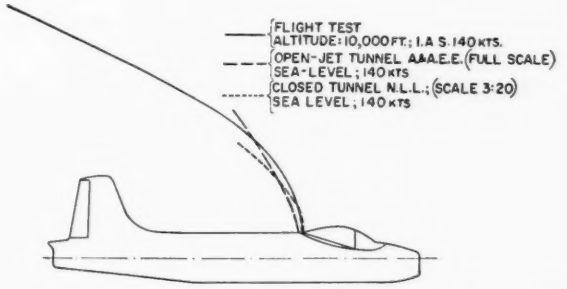

FLIGHT TEST
ALTITUDE: 10,000 FT.; I.A.S. 140 KTS.
OPEN-JET TUNNEL A&A.E.E. (FULL SCALE)
SEA-LEVEL; 140 KTS
CLOSED TUNNEL N.L.L.; (SCALE 3:20)
SEA LEVEL; 140 KTS

FIGURE 45. Trajectories of cockpit hood of the Fokker S-14 after jettisoning in wind tunnel and free flight.

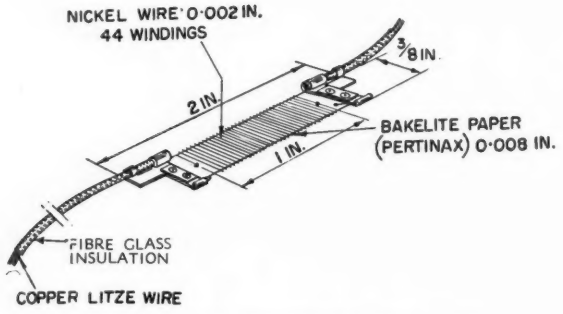


FIGURE 46. N.L.L. temperature sensing element.

Apparatus is available for calibrating static and fatigue testing machines, mechanical extensometers, dynamometers, etc., as well as equipment for non-destructive testing.

The structures laboratory disposes of a test frame for testing small wings and fuselages, but full-scale tests on complete aeroplanes are done by the Fokker factory. For instance, a programme of static tests on the F.27 Friendship has recently been completed (Fig. 47) and fatigue tests will be made this year.

Theoretical research on methods for computing stresses and deflections of *swept wings* has been going on for about six years. Approximate methods have been developed, employing the well-known minimum-energy principles with systems of internal stresses or displacements. Upper and lower bounds have been determined in order to judge the accuracy of the results. A swept box, for which most of the calculations have been made, was built and tests to verify the computed results are proceeding (Fig. 48).

Problems of *post-buckling behaviour of stiffened plates*, loaded in compression and shear have been extensively investigated, both by theoretical and experimental methods from 1941 onwards (*see, e.g.* Refs. 61 to 65). Since the tests on webs loaded in shear and compression were in reasonable agreement with Koiter's theoretical predictions[63], a complete numerical evaluation of the theory was made. The results, valid for the elastic range, are given in the form of diagrams in Refs. 64 and 65, as well as examples of their application.

More recently, some series of tests to determine the effective width in compression of stiffened flat plates of various aluminium alloys in the plastic range were made[66, 67]. In these tests, the stiffeners were represented by knife edges. Fig. 49 shows a three-bay specimen after test and Fig. 50 presents a typical load-deflection diagram and also shows in the upper left part the way in which the buckling stress was determined experimentally (W and L are amplitude and half wave length of the waves, σ = mean compressive stress, ε = mean compressive edge strain).

The test results showed that the post-buckling behaviour and the ultimate load of the plate could be predicted, with good accuracy, from the stress-strain curve of the material and a simple adaptation of the theoretical results for the elastic range, from Ref. 61. Further tests will be made on plates with glued-on strips, representing the flanges of stiffeners bonded to the sheet.

The post-buckling behaviour under axial compression of a narrow cylindrical panel with hinged edges was treated theoretically quite recently[68]. It appeared that the initial post-buckling stage is stable only for very narrow panels and it was conjectured that in the advanced post-buckling stage the behaviour of such a panel will approach that of a flat panel.

FIGURE 47. Static load test on F-27.

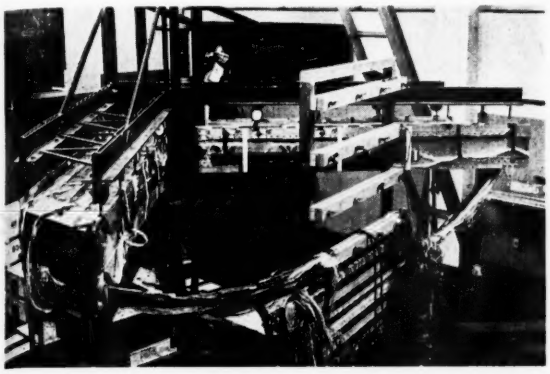


FIGURE 48. Test set-up for strain and deflection measurements on swept box.

Theoretical and experimental investigations concerning the elastic overall instability of *flat sandwich plates* have been made[69, 70]. Owing to initial eccentricities and the low face-to-core strength of the tested panels, the test results were less favourable than predicted by the theory. Tests on sandwich plates of modern manufacture would probably show better agreement with the theory.

The trend to heavier skin gauges gave rise to some investigations on *plastic buckling* of plates. The results of the N.L.L. tests were in agreement with those of tests made elsewhere. In Ref. 71 a new semi-empirical formula for computing the buckling load has been proposed. In connection with this work, a theory has been developed on plastic flow in relation to anisotropic hardening in plastic deformation of an initially isotropic material[72].

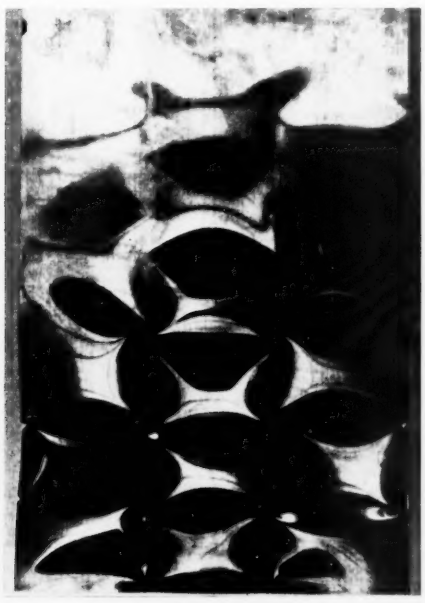


FIGURE 49. Three-bay specimen after compressive test.

In close co-operation between the N.L.L. and the Fokker Company some series of tests on important structural components of aeroplane wings have been made. One of these was concerned with the strength and stiffness properties of *shear webs with lightening holes.* After the development of a special test set-up, eliminating as far as possible undesirable secondary effects, 84 webs were tested. In the reports on the tests, comparisons have been made with similar American and Swedish investigations[73, 74]. Fig. 51 shows a specimen after the test. The two wide flat plates introduced the shear load in a representative way. Another test series was related to the torsional strength and stiffness of *wing leading edge boxes*[75]. Fig. 52 shows a test specimen mounted to the N.L.L. test frame and Fig. 53 is an example of one of the modes of failure.

In connection with the design of the wing, fuselage and tail surfaces of the Fokker F.27, some 200 stiffened panels have been tested in compression or shear; most of these panels had stiffeners Redux-bonded to the skin. Fig. 54 gives an example of a 75 S-T wing panel that failed at a compressive load of 118 metric tons. A semi-empirical method for predicting the ultimate compressive strength of bonded stiffened panels is being developed by the Structures Department of the Fokker Company. A more refined, but more complicated, method has been published by van der Neut[76].

2.4.2. *Fatigue*

Since the erection of a number of modern fatigue machines around 1950, fatigue tests have formed an important part of the structures and materials research at N.L.L.

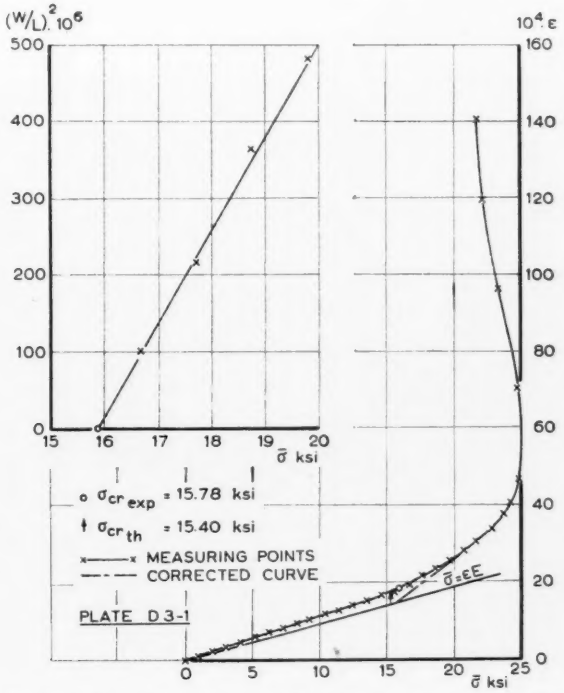


FIGURE 50. Typical load-deflection diagram (three-bay specimen of 3 mm. 24 S-T sheet).

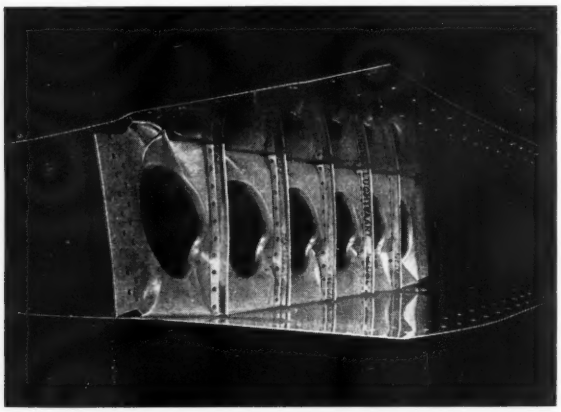


FIGURE 51. Shear web specimen after test.

Many of the test programmes are intended to aid the aircraft industry in the design of important structural joints and other fatigue-sensitive components. Various extensive series of tests on riveted joints, Redux-bonded joints, lugs with and without interference-fits, have been made to determine fatigue diagrams. As an example, Fig. 55 shows a standard riveted joint in the 10 ton high frequency fatigue machine and a similar joint mounted in the 6 ton Schenck pulsator. Refs. 77, 78 and 79 give some recent results: Fig. 56 gives two fatigue diagrams of two-row snap riveted lap joints of Alclad 24 S-T and 75 S-T aluminium alloy of 0·8 mm. sheet thickness, 3 mm. rivet diameter and 20 mm. rivet spacing.

In order to get an impression of the *fatigue properties of bonded components*, comparative fatigue tests in repeated compression have been executed on Redux-bonded and riveted stiffened panels[80]. The maximum cyclic loads were 75, 60 and 45 per cent of the static strengths of the panels (12 tons for the bonded panel and 10 tons for the riveted panel), at which the thin skin (0·5 mm.) has clearly buckled. Fig. 57 shows a bonded panel after failure in the fatigue test and Fig. 58 gives a survey of the test results.

Fatigue tests in compression and three-point bending have also been carried out on spar booms, manufactured by bonding together a number of thin-sheet angles and flat plates[81]. The *S-N* curve for the maximum tensile stress in these spar booms was nearly the same as the *S-N* curve in repeated tension of the sheet material, a very satisfactory result.

Some fatigue investigations of a more general nature are concerned with *cumulative damage and crack propagation*. A rather large number of cumulative damage tests have been performed to verify the linear cumulative damage hypothesis $\Sigma (n/N) = 1$. The first tests were conducted on unnotched and simply notched axially loaded specimens[82, 83]. Each test was repeated 10 or 20 times to obtain a statistically justified picture. From the results it was learned that the accumulation of fatigue damage did not take place in the simple way as suggested by the linear cumulative damage hypothesis. From a comparison with the results of other investigations[84] it turned out that unnotched specimens, simply notched specimens and more complicated specimens, exhibit a quite different behaviour under a cumulative damage loading. Also, factors such as mean stress and type of fatigue load programme, determined the cumulative damage behaviour. Consequently it was decided to perform cumulative damage tests as realistically as possible. Tests are now performed on riveted

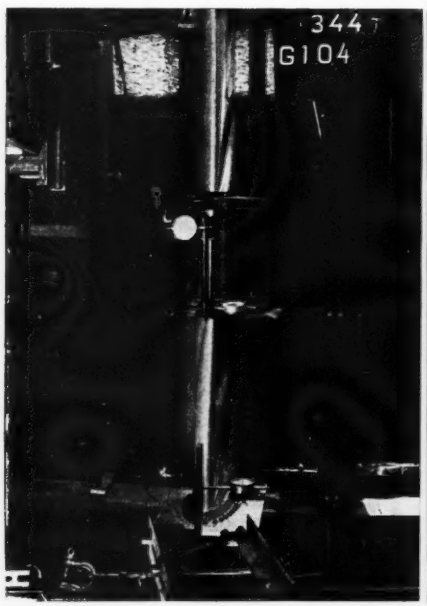


FIGURE 52. Torsion box specimen mounted to test frame.

FIGURE 53. Example of failure of torsion box specimen.

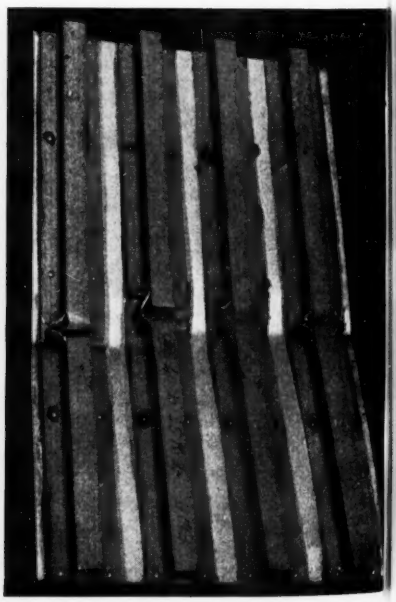


FIGURE 54. 75 S-T stiffened panel aft compression test.

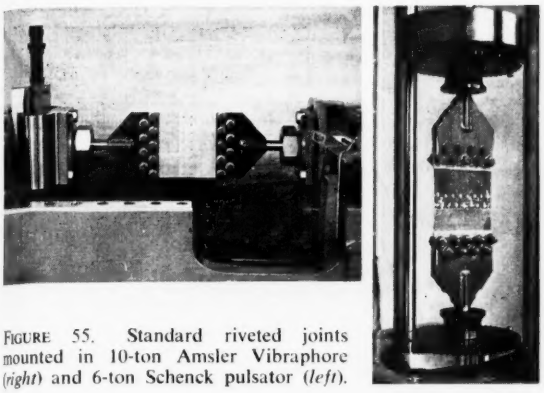


FIGURE 55. Standard riveted joints mounted in 10-ton Amsler Vibraphore (*right*) and 6-ton Schenck pulsator (*left*).

joints of 24 S-T and 75 S-T alloy (comparable to D.T.D. 610 B and D.T.D. 687 A) which are axially loaded in Amsler Pulsators employing a positive constant mean stress. Tests with simple load sequences, as well as programme tests with load spectra, have been performed. No detail results will be given here as the test programme has not yet been completely finished. A full description will be published shortly.

Fatigue crack propagation has been studied for two reasons[85]. Firstly the consequences of a fatigue crack in an aircraft structure are important with respect to the safety against catastrophic failure. Therefore aircraft structures, aircraft materials and their crack stopping properties should be studied. Secondly, the crack growth studies allow a more refined theoretical approach to several fatigue problems, such as notch effect, size effect, scatter, cumulative damage, effect of

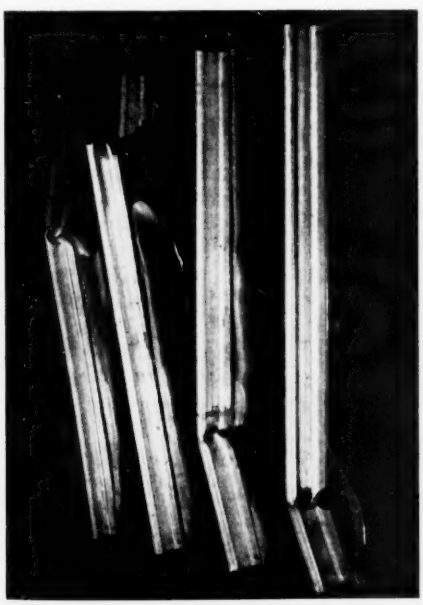


FIGURE 57. Example of bonded stiffened panel after compressive repeated-load test.

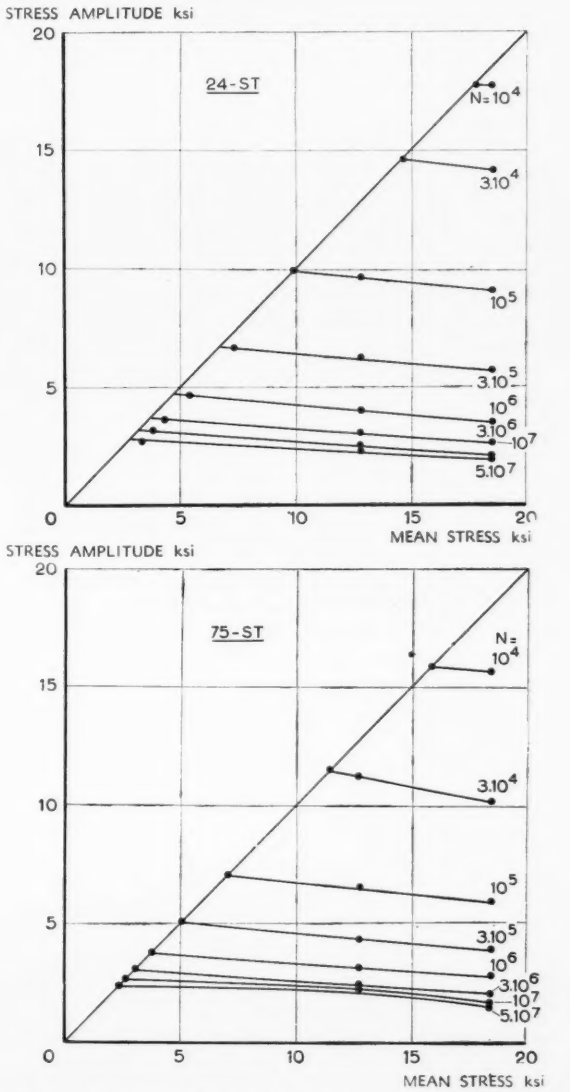


FIGURE 56. Example of fatigue diagrams of two-row riveted lap joints.

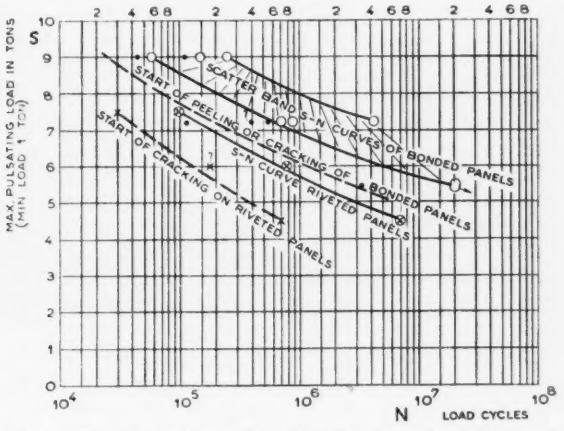

MAX. PULSATING LOAD IN TONS (MIN. LOAD 1 TON)
SCATTER BAND S-N CURVES OF BONDED PANELS
START OF PEELING OF
CRACKING OF BONDED PANELS
S-N CURVE RIVETED PANELS
START OF CRACKING ON RIVETED PANELS
N LOAD CYCLES

FIGURE 58. Comparison of results of compressive fatigue tests on bonded and riveted stiffened panels.

surface finish, effect of mean stress, fatigue under combined stresses, and so on. These problems are still waiting for a physical solution.

2.4.3. *Other subjects*

Apart from the static and fatigue testing of bonded metal components already mentioned in the previous sections, a great deal of work has been done on other aspects of metal bonding, both by the Fokker Company and at the N.L.L. This comprises mainly, research on manufacturing techniques of bonded structures as well as some tests on the effect of temperature variations and manufacturing defects on the mechanical properties.

Two other fields of research in which fairly considerable efforts have been, or are being, expended, may be mentioned.

The application of glass fibre-reinforced plastics and the determination of their static and fatigue properties is a subject of research both at Fokker and at N.L.L. (*see, e.g.* Ref. 86). A number of parts of the F.27 are being made from this material.

Ultrasonic testing has been applied with success to the detection of cracks in jet engine rotor blades. Special probes were built for this purpose. The possibility of using ultrasonic techniques for testing bonded joints is being investigated.

3. Technical University at Delft

3.1. INTRODUCTION

In the early twenties research in the field of fluid dynamics was started at Delft Technical University. In his laboratory Prof. Dr. J. M. Burgers performed his well-known experiments on the transition phenomena on a flat plate[87]. The laboratory of Fluid Dynamics of the University has since then been engaged in work on general problems of fluid and gas dynamics—among which the phenomena in turbulent flow continued to be a major subject—and fluid problems in the field of mechanical engineering.

In 1940 the Technical University instituted a separate Department of Aeronautical Engineering. During the war the activities of this Department could only be on a very limited scale and a real start was not made before 1945. In the following years the efforts of the staff were at first mainly directed to the study of the developments in the aeronautical field. Later on, some time became available for research primarily aimed towards making a contribution to the education of research engineers. As the following survey shows, until now most of the investigations had the purpose of giving staff and students access to measuring techniques and some interesting, already known phenomena. It has been proved, however, that such projects of a rather simple nature gradually develop into research work of a more advanced type.

In general the research of the Department is directed to three main fields: the study of the application of boundary layer control, the study of flying qualities of aircraft and of problems related to the development of aircraft structures.

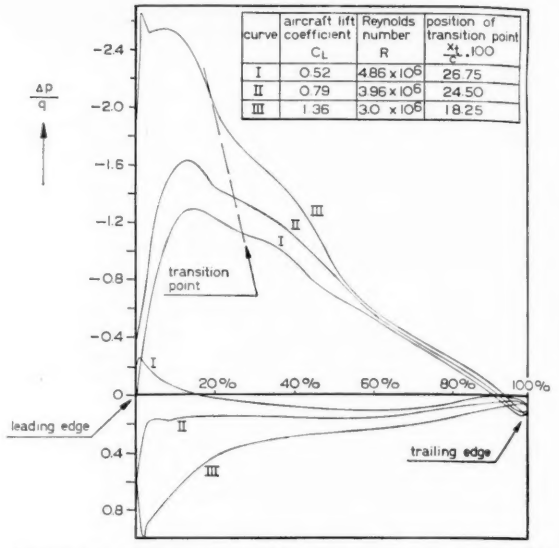


FIGURE 59. Pressure distributions measured on a wing section in free flight.

3.2. BOUNDARY LAYER RESEARCH

The first measurements in this field in flight were made in the period 1949-1952 on a section of the wooden wing of a single-engined monoplane. Some typical results are shown in Figs. 59-61. For a range of angles of attack the following characteristics have been measured:

(*a*) static-pressure distributions with pressure orifices (Fig. 59);

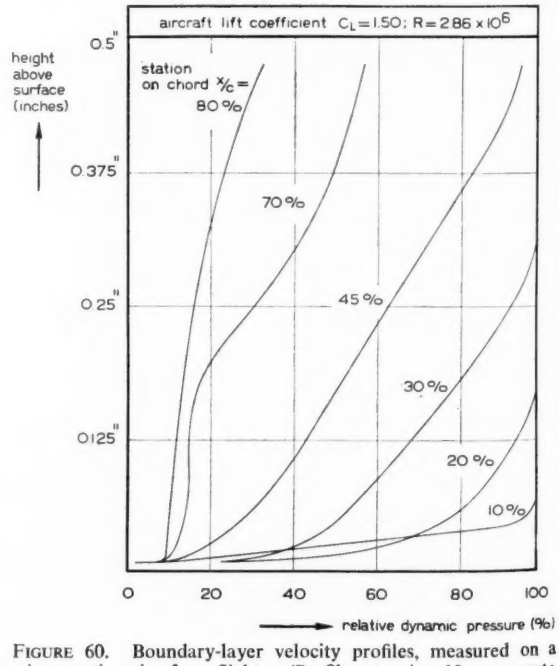
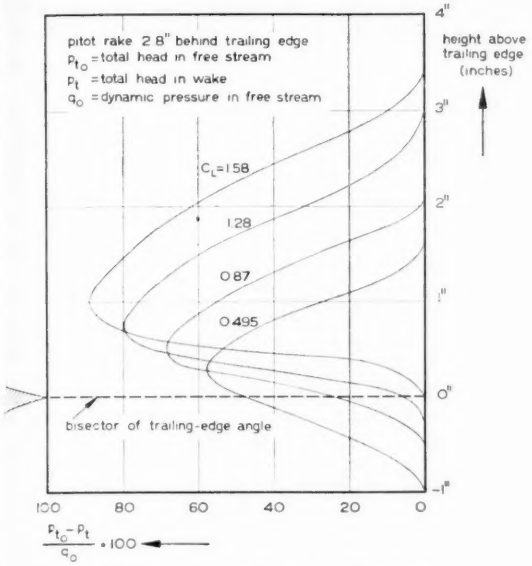


FIGURE 60. Boundary-layer velocity profiles, measured on a wing section in free flight. (Profile at $x/c=10$ per cent: laminar, other profiles turbulent.)



aircraft lift coefficient C_L	Reynolds number R	profile drag coefficient c_{d_p}	position of transition point (upper surface) $\frac{x_t}{c}\cdot 100$
0·495	$4\cdot97\times10^6$	0·0078	27
0·87	$3\cdot76\times10^6$	0·00965	23·75
1·28	$3\cdot10\times10^6$	0·0124	19·5
1·58	$2\cdot79\times10^6$	0·0165	14·5

FIGURE 61. Total-head loss in wake, measured behind a wing section in free flight.

(*b*) velocity profiles in the boundary layer with Pitot-creepers (Fig. 60); from these profiles the position of the transition point could be estimated;

(*c*) the total-head in the wake with a Pitot-rake (Fig. 61), from which the profile drag coefficient has been derived.

During these investigations, it became evident that it would be useful to develop a method for the experimental estimation of the transition point of the boundary layer without disturbing the flow around the wing. With such a method it would be possible to determine the position of the transition point simultaneously with the chordwise pressure distribution and the wake-drag.

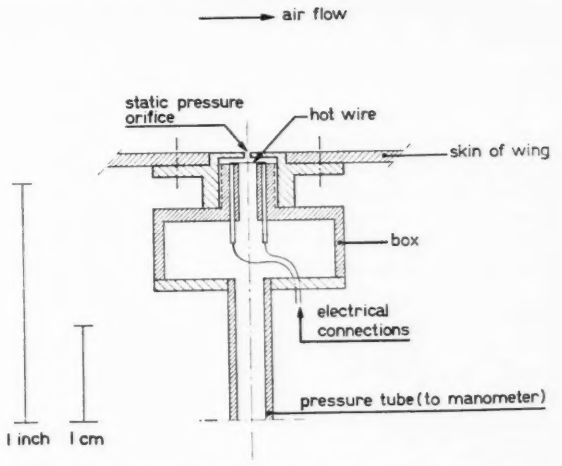


FIGURE 62. View of hot-wire device underneath the wing surface.

The method developed for this purpose will be described in some detail[88]. Inside the wing surface a small Perspex box has been fixed between the orifice for the measurement of the static pressure and the pressure tube leading to the manometer; the device is shown in Fig. 62. At the top of the box, under the wing surface, a hot wire was exposed to the air. The output of the hot wire was amplified and fed into an oscilloscope. The possible influence of the engine noise on the pictures obtained on the screen was eliminated with the help of a filter between the amplifier and the oscilloscope.

Figure 63 shows some of the results of the investigations in free flight. The curve gives the relative dynamic pressure at a height of 0·008 inches (0·2 mm.) above the wing surface as a function of the aeroplane lift coefficient for the 16 per cent chord station. The

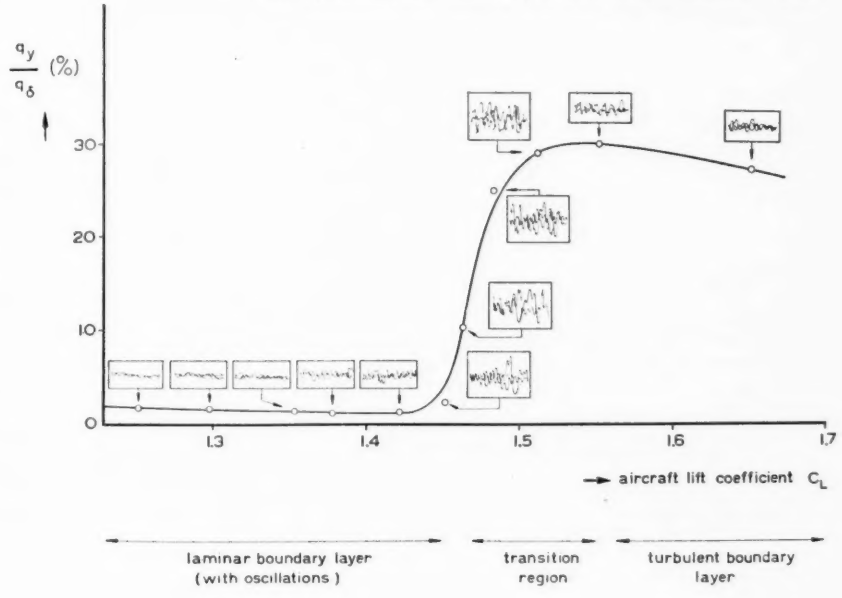


FIGURE 63. Correlation of the oscilloscope-pictures with the character of the boundary layer at the 0·16 chord position (q_y = measured dynamic pressure at y = 0·008 in. above wing surface, q_δ = local dynamic pressure outside boundary layer.)

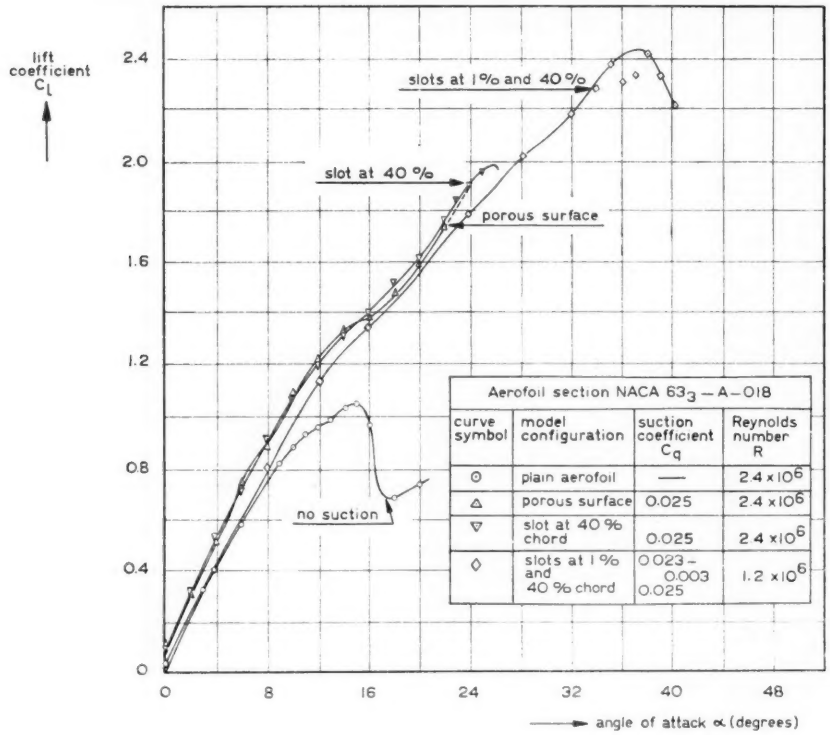

lift coefficient C_L
2.4
2.0
1.6
1.2
0.8
0.4
0
slots at 1% and 40%
slot at 40%
porous surface
no suction
0
8
16
24
32
40
48
angle of attack α (degrees)
Aerofoil section NACA 63₃ – A – 018
curve symbol | model configuration | suction coefficient C_q | Reynolds number R
⊙ | plain aerofoil | — | 2.4 x 10⁶
△ | porous surface | 0.025 | 2.4 x 10⁶
▽ | slot at 40% chord | 0.025 | 2.4 x 10⁶
◇ | slots at 1% and 40% chord | 0.023 – 0.003 0.025 | 1.2 x 10⁶

FIGURE 64. Lift curves for two-dimensional wing with boundary layer suction.

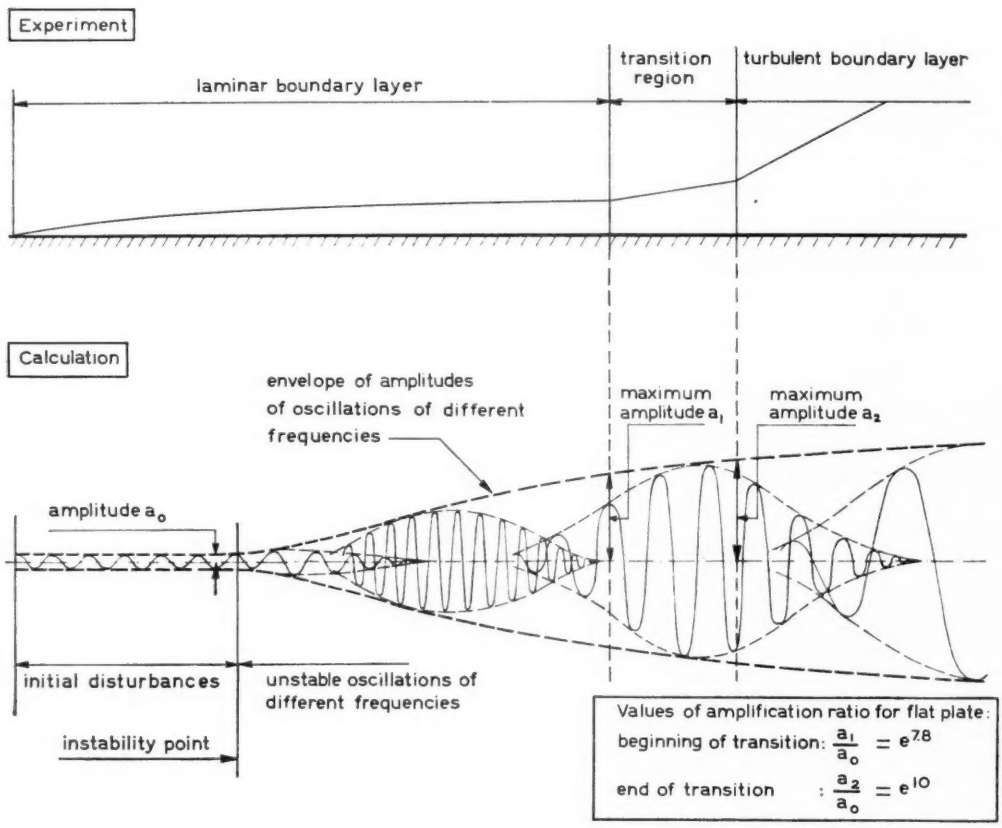


FIGURE 65. Amplification of unstable disturbances in the laminar boundary layer.

sudden jump in the curve indicates the lift coefficient for which the transition point passes the 16 per cent station.

The correlation between the results of the pressure measurements and the pictures obtained on the oscilloscope can be seen clearly. For a laminar boundary layer a straight line appears. In some cases near the transition point sinus-shaped oscillations have been found, with a frequency of around 1500 Herz. It is believed that these oscillations indicate the increasing instability of the boundary layer and correspond with the oscillations found by Schubauer and Skramstad in the U.S.A. during their investigations on the behaviour of the laminar boundary layer on a flat plate[41].

When transition starts, the picture on the screen shows irregular, large oscillations, the amplitude of which decreases slightly when the turbulent boundary layer is fully developed. Fig. 63 indicates that the local character of the boundary layer can be investigated with the described equipment.

When the low turbulence wind tunnel of the Department—which will be described later—was completed, an investigation was started of the problems of *boundary layer control by suction*. To obtain some experience in this field a simple two-dimensional model, which could be provided with slots at one per cent and 40 per cent chord or a porous surface from 30 per cent chord to the trailing-edge was tested. Results of the lift measurements are shown in Fig. 64; they agree in general with the investigations of other institutes. In addition to the lift, the wake-drag of the aerofoil with suction through the porous surface has been measured. Due to a relatively simple construction of the model, a large amount of suction was necessary to obtain a laminar boundary layer along the whole chord and no reduction in total drag (wake-drag + drag related to the power for suction) in relation to the plain wing could be found.

For an efficient design of aerofoils with boundary layer suction for drag reduction, it is necessary to dispose of a method for *predicting the position of the transition region of the laminar boundary layer*.

It was found that such a method[89] could be based on the assumption that a boundary layer becomes turbulent when the amplification ratio of the unstable sinusoidal oscillations in the laminar boundary layer, as calculated by the Tollmien-Schlichting-stability theory, exceeds a given value.

The amplification ratio has been defined as the amplitude of the oscillation with maximum amplification at the station considered, divided by the amplitude of the initial disturbances (Fig. 65).

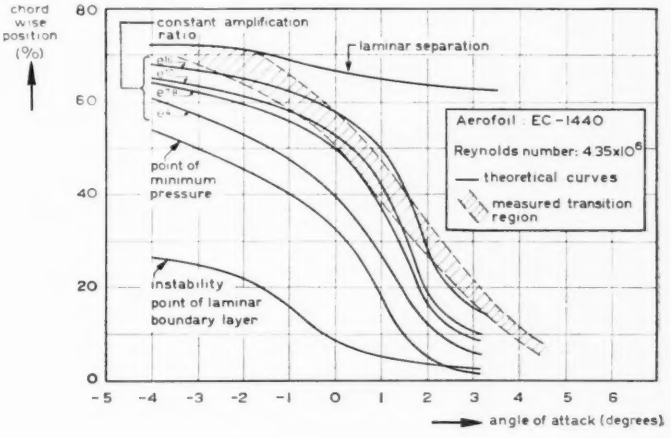


FIGURE 66. Results of boundary layer calculation for an aerofoil.

For the plate a comparison between the calculations and available experimental data on the transition region, indicated that at the beginning of transition the amplification ratio equals $e^{7\cdot8}$ ($\cong$ 2,500) and at the end of transition e^{10} ($\cong$ 22,000).

For the aerofoil section EC 1440 the same calculations have been performed and compared with the experimentally determined transition region in the low-turbulence wind tunnel. The most important results are shown in Fig. 66 where, for the EC 1440 section, curves for constant values of the amplification ratio are given, together with the measured transition region. For zero angle of attack the beginning of the transition is found at exactly the same amplification ratio as in the case of the flat plate. For angles of attack different from zero, the differences can partly be explained by inaccuracies, caused by imperfections in the boundary layer calculations, which might be improved in future.

After the investigations described had been completed a report by Smith (U.S.A.) dealing with the same subject became available[90]. A similar method is described for estimating the transition region; for a large number of aerofoils and bodies of revolution almost the same value has been obtained for the amplification ratio of the oscillations at transition as that mentioned above.

3.3. FLIGHT TEST RESEARCH

For investigations in the field of flight-testing the Department of Aeronautical Engineering disposes of an Auster J.5B Autocar, a single-engined light aeroplane, with a seating capacity of up to four persons.

A result of the flight tests performed is shown in Fig. 67. It gives some measurements on the static longitudinal control characteristics of the Auster J.5B. The figure shows the positions of the centre of gravity for neutral stability with stick fixed and constant throttle setting as derived by two different methods.

The upper curve has been obtained by extrapolating to zero the slope of the trim curves (elevator angle versus air speed), which have been measured for this purpose at three different c.g. positions.

The values given by the lower curve have been determined from the slope of the moment curve

(C_m against C_L) at a fixed elevator angle for a certain c.g. position. This moment curve has been derived from the same flight tests.

Figure 67 illustrates that, when concluding to the c.g. position for neutral stability from the C_m against C_L curve at a constant elevator angle, considerable errors can result (up to 20 per cent mean aerodynamic chord in this case).

These errors are basically due to the fact that the slope of the moment curve at a constant elevator angle has, inevitably, been determined in points in which C_m is unequal to zero. If there is a strong influence of propeller slipstream at the horizontal tail, the slope of the moment curve C_m against C_L is, however, also dependent on the value of the elevator angle.

The given example indicates the desirability in wind tunnel model tests with running propellers, to adjust the elevator angle for zero pitching moment at each lift coefficient at which the slope of the moment curve has to be determined.

For general studies in the field of flight dynamics an analogue computer of modest size has been designed and built at the Technical University. The main feature of this computer is the low-drift quality of the amplifiers, permitting computations of a rather long duration on a true time scale.

An impression of the results obtained is given by Fig. 68. The picture shows a comparison between the motions of a conventional twin-engined medium-sized

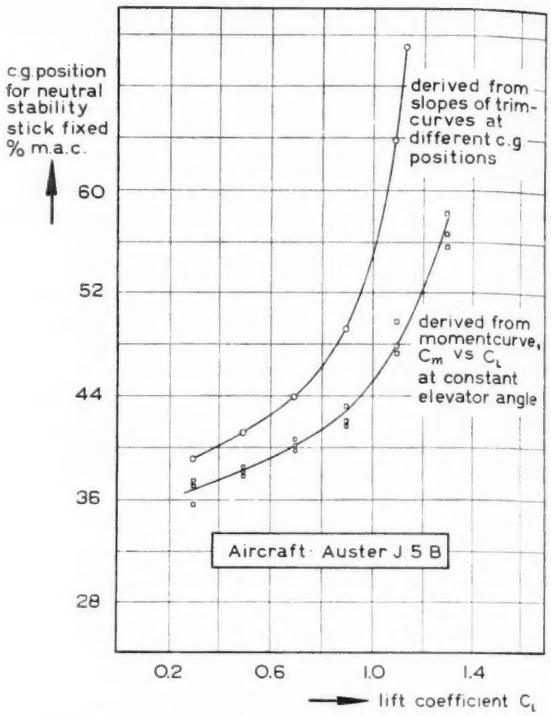


FIGURE 67. C.g. position for neutral stability stick fixed, at constant throttle setting, against lift coefficient.

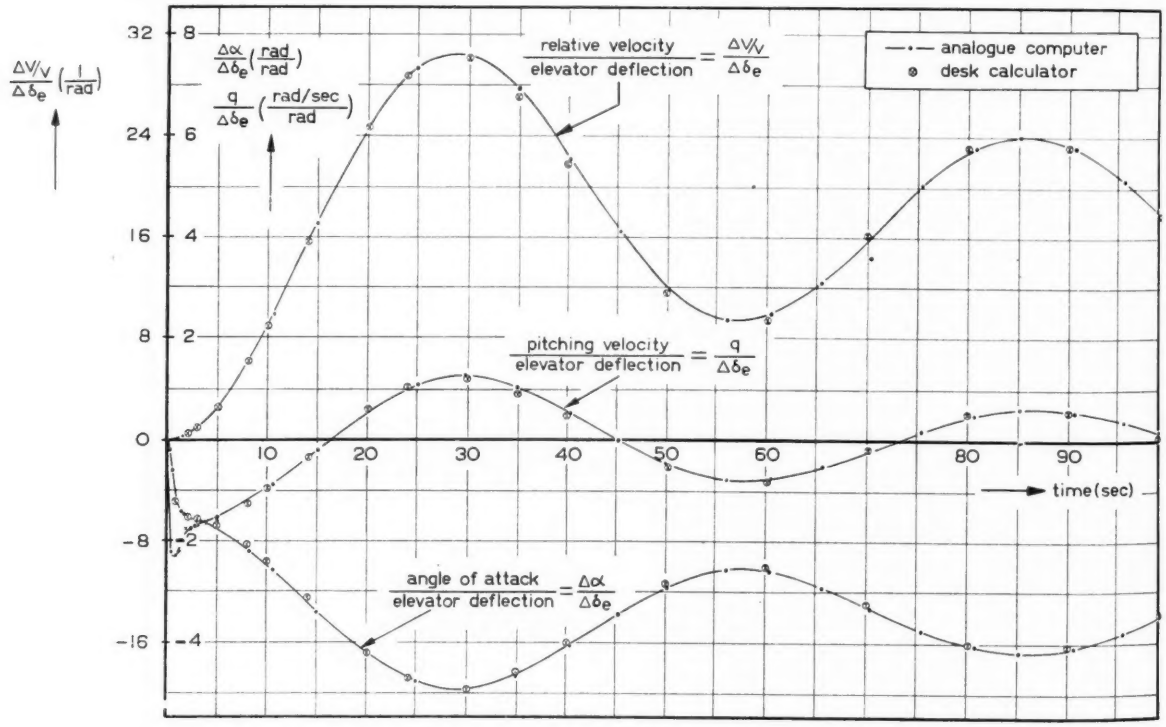


FIGURE 68. Comparison of the response due to an elevator step deflection for a twin-engined medium-sized aircraft as estimated by means of the analogue computer and of a desk calculating machine.

aircraft due to an elevator step deflection, as calculated by means of the analogue computer and by means of a desk calculating machine.

It appears that after the relatively long period of 100 sec. no appreciable drift occurs; due to this feature the computer is well suited for tests in combination with automatic control equipment.

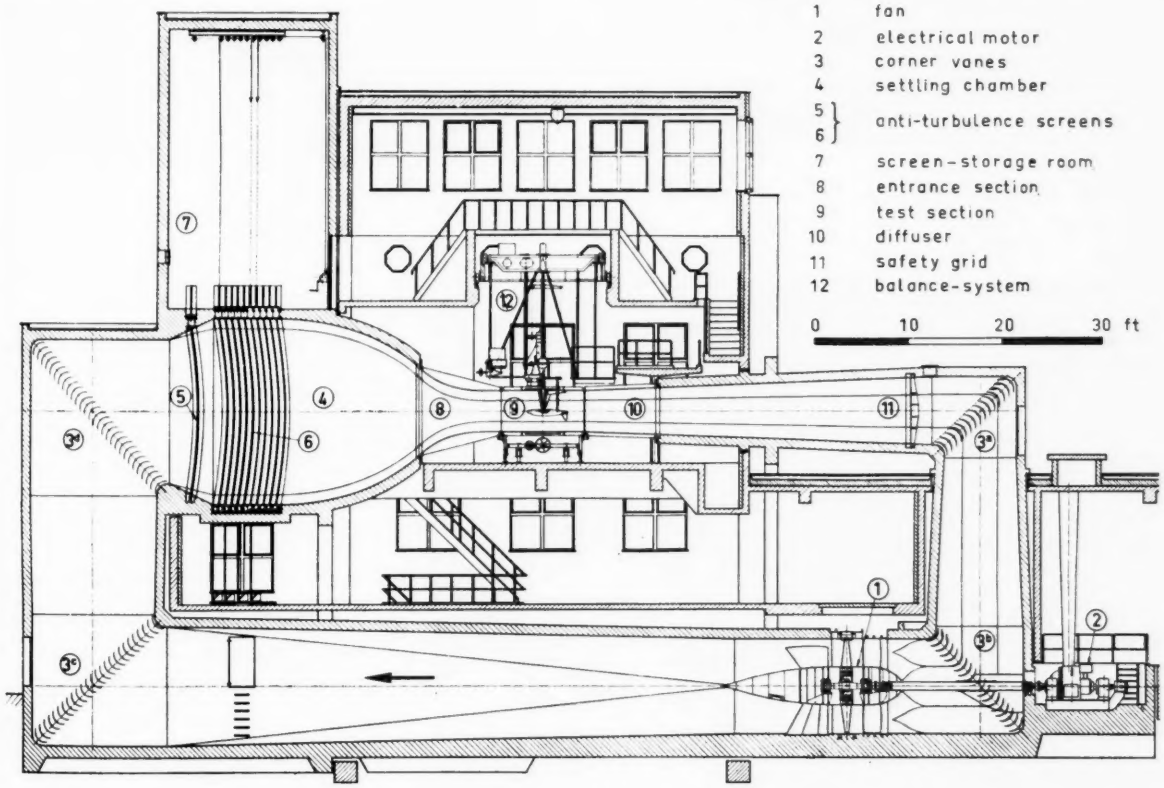
3.4. WIND TUNNELS OF THE DEPARTMENT OF AERONAUTICAL ENGINEERING

The main wind tunnel of the Department is a 4 ft. × 6 ft. low turbulence tunnel with a maximum speed of 400 ft./sec.[91]. Fig. 69 shows a vertical longitudinal section of the wind tunnel and some of the characteristics. The tunnel is a normal closed type, the walls of the channel being of reinforced concrete coated with bitumen. The settling chamber has been provided with 8 anti-turbulence screens, which can be hoisted into a screen room on top of the channel. To eliminate excessive temperatures of the air in the test section during long runs under full power, the rows of guide vanes in the first and second corner of the channel behind the test section are water-cooled.

As an interesting point of the wind tunnel design the interchangeable test section can be mentioned. At present there are four such sections which can be exchanged in about a quarter of an hour. The test sections not in use are moved into another room at the same floor, separated from the test room. The system proves to be quite satisfactory and two more test sections are now under construction.

Figure 70 gives a view of the test room with one of the test sections installed. Above the test section the balance system for force measurements can be seen. This system consists of six automatic riderweight balances, the output of which is transmitted to a small mechanical computer, giving the components relative to axes through the centre of the model. A general impression of the wind tunnel building can be obtained from Fig. 71.

In the same building the Department of Aeronautical Engineering has a small supersonic blow-down wind tunnel under construction. The table in Fig. 72 gives the main features of this tunnel. Due to the high pressure of the storage air it was possible to design the tunnel without diffuser; the air leaves the working



test section	:	6 x 4 ft (1.80 x 1.25m)	Reynolds number
contraction ratio	:	17.9 : 1	complete aircraft model : 2×10^6
maximum speed	:	400 ft/sec	two-dimensional aerofoil : 5×10^6
			max. power of d.c. motor : 700 hp(1150 rpm)

FIGURE 69. Longitudinal section of the low-speed wind tunnel. Delft Technical University.

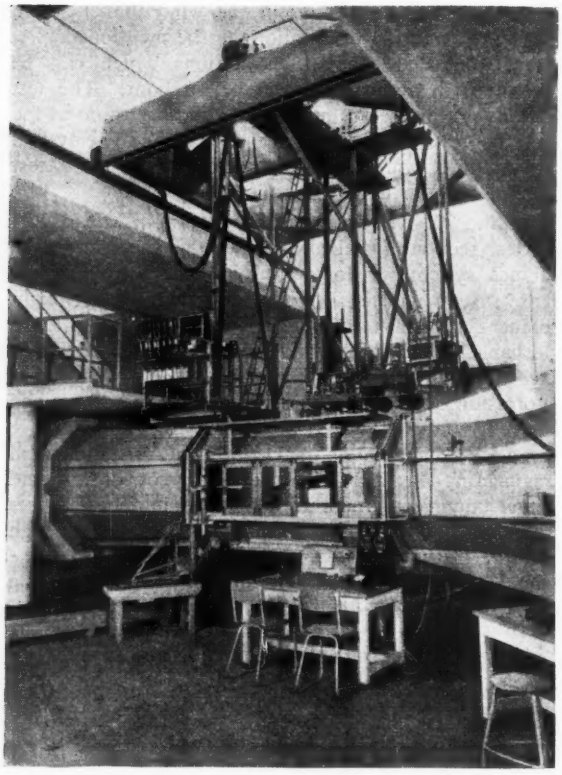


FIGURE 70. Test section and balance system of the low-speed wind tunnel. Delft Technical University.

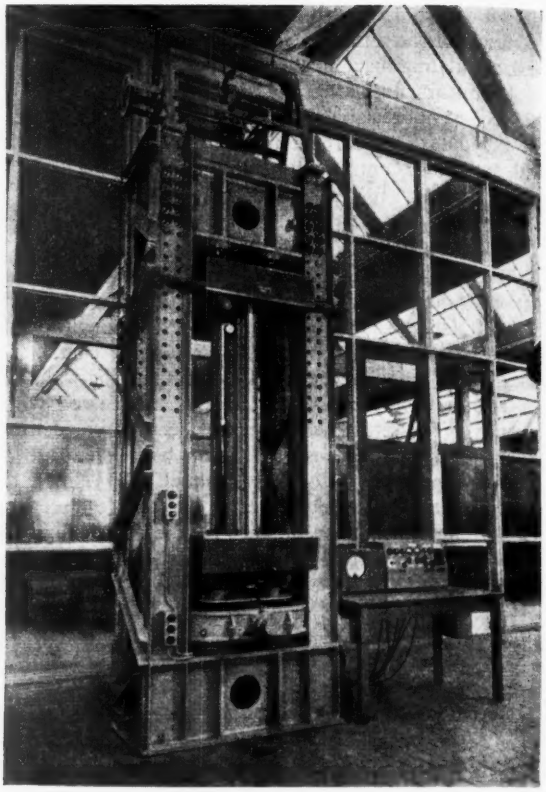


FIGURE 73. The compression testing machine of the Department of Aeronautical Engineering. Delft Technical University.

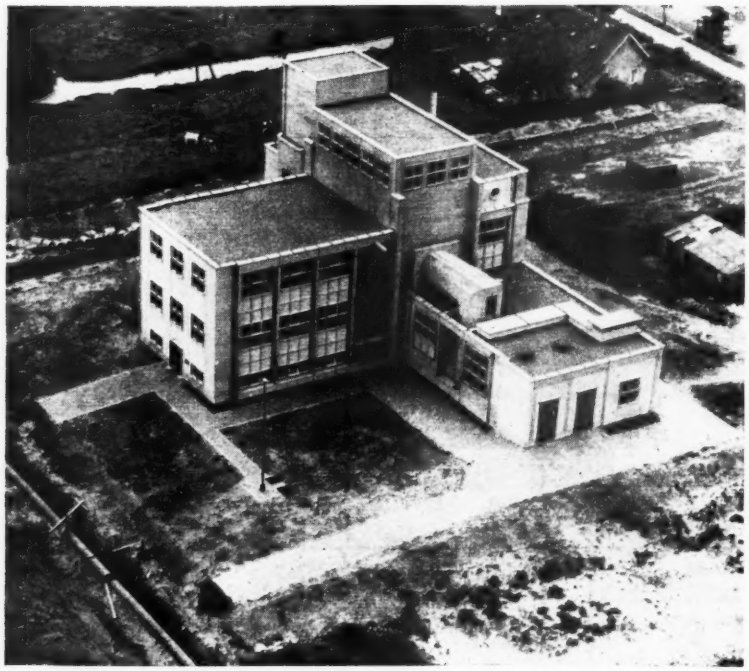


FIGURE 71. General view of the wind tunnel building. Delft Technical University.

Main features of the supersonic wind tunnel

Volume of air storage vessel	:	250 cu. ft.
Max. pressure of air storage vessel	:	2200 lb./sq. in.
Size of the working section	:	6 in. × 6 in.
Mach number range	:	1·5 – 3·5
Running time with pressure drop of 100 atm.	:	1·5 – 2 min.
Pumping time from 50-150 atm.	:	5½ hr.

FIGURE 72. Main features of the supersonic wind tunnel, Delft Technical University.

section as a free jet into the room. The main advantage of this type of tunnel is the easy accessibility of the models and the complete freedom in model mounting.

3.5. STRUCTURAL RESEARCH

Apart from the usual equipment for testing aircraft structures, the structures laboratory has been equipped with an 80-ton compression testing machine (Fig. 73), designed by the department. The leading idea was to obtain a very stiff machine, longitudinally as well as laterally. The lower platten is mechanically operated, since hydraulic operation results in low longitudinal stiffness. Test specimens up to 5 ft. length and 3 ft. width can be investigated.

So far buckling tests on stiffened panels have been performed. Due to its longitudinal stiffness characteristics the machine is very suitable for investigating the explosive type of buckling phenomena such as occurs in cylindrical shells.

A straightforward method has been derived for solving numerically the local buckling problem of stiffened panels with the stiffeners riveted to the skin.[76] This work is being continued to include structures where the stiffeners are bonded.

Skin buckling under the combined action of temperature gradients and compressive load, such as occurs in multi-web wings of supersonic aircraft, has been investigated. Buckling coefficients have been obtained for a family of temperature distributions. A method has been derived for determining the correction, induced by thermal stresses of the buckling coefficient, if the isothermal load condition is known.[92] Post-buckling behaviour of thermally loaded and externally strained skin panels has been investigated. It was found that the load increment beyond buckling load in the isothermal case is a good approximation for the load increment beyond buckling load in the thermal case.[93]

Acknowledgment

In the preparation of this survey several collaborators at the N.L.L. and at Delft have thoroughly assisted and I wish to thank them all, especially Mr. L. L. Th. Huls.

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DISCUSSION

DR. W. CAWOOD (Director-General of Scientific Research Air, Ministry of Supply, *Associate Fellow*): He had a great deal of pleasure in opening this discussion as it gave him the opportunity to pay a tribute to Professor van der Maas who had done so much to build up the science and practice of aeronautics in his country.

Not long ago one of their lecturers gave a very high world placing in the field of military aeronautics to a small European nation and that gave rise to some controversy at the time, but he was sure no one would disagree that Holland, with that magnificent organisation —the K.L.M. running civil airlines, the great firm of Fokker, the N.L.L. and the University of Delft—occupied a leading position in the civil field. That position they all knew was in no small measure due to Professor van der Maas. His contributions, both as the Head of Flight Test at N.L.L. before the war and at the Delft Technical University since, were well known. Possibly less well known was the great amount of work which he had devoted to the planning of these programmes of work and the planning of the new technical facilities at N.L.L. in his capacity of President of the Netherlands Aircraft Development Board and of the Board of the N.L.L. itself.

In addition to all this work inside Holland, Professor van der Maas had also devoted himself to international co-operation in aeronautics. Recently he had been lucky enough, succeeding the President, Mr. E. T. Jones, in serving with Professor van der Maas on the executive committee of AGARD and having seen him in action he had been very greatly impressed by his very

sincere belief in the necessity for scientific co-operation on an international basis.

These views of his were reflected in the general policy of N.L.L., which was, he believed, the only laboratory in the world to provide international aeronautical reference library service and he was glad to see that in this country they had been able to help by providing facilities at Boscombe Down for the canopy jettison tests. Another example of this pioneer spirit of the Dutch, which gave them this international influence so large in proportion to their size, was the fact that K.L.M., although by no means the largest international airline, he believed flew more unduplicated route miles than any other airline in the world.

It was interesting to see that they were not undertaking any engine work, but also very gratifying that in their latest civil aeroplane they had turned to this country for the engines. He thought this showed great wisdom and he hoped they would continue to look here for power plants!

Professor van der Maas had covered a very wide field of work in his lecture which was fascinating to listen to, not the least because of his wonderful command of their language. He wished the British could go to the Continent and give lectures with the same fluency—but very few of them could. With such a wide cover he found some difficulty in choosing appropriate subjects for discussion—even Professor van der Maas could not be a specialist in all of them. He would like to raise four points, two general and two technical.

The first concerned the business of planning and financing the Dutch aeronautical research programme. In the United Kingdom, aeronautical research was carried out in government establishments, in universities and in the Industry, and to the extent to which it was sponsored directly or indirectly by public monies or government funds, the programme largely reflected, first of all, one must admit, the military policies of the Ministry of Defence. It reflected the civil requirements of the airline corporations. It relied to a large extent on the recommendations of the Aeronautical Research Council, an advisory body partly independent and partly official, but which he thought was regarded as an independent body and, of course, there was a great deal of self-generated research within the Ministry of Supply and its establishments. He wondered if there was any similar organisation in Holland. For instance, did the Dutch Scientific Advisory Committee correspond with the Aeronautical Research Council? He would be interested to hear how the Dutch did lay down their programme and decide what to work on.

Whatever their machine, there was no doubt about the high standards which were set and achieved in the work which they had heard about that night. To him it seemed a surprisingly large return for an annual expenditure of £200,000. It was a wide programme and he had the feeling that it was possibly a little wide for the size of the staff available and they all knew how important it was not to overload scientists with too many different fields of work. He would like to hear Professor van der Maas' views.

He would like to know Professor van der Maas' views on future international co-operation in aeronautics. He knew, for instance, that he was very disappointed that Great Britain did not take part fully in the recent European Aeronautical Conference in Holland. Some of them attended in the capacity of private observers and he, personally, was very glad to have been there because the standard of lectures was very good and the discussions were extremely realistic and interesting.

On the other hand, there were so many conflicting claims on their time these days. They all had their national learned societies, the Royal Aeronautical Society was one of them, and all countries must have them, but they seemed to have too many of these international bodies which took more time because of the travelling involved. They had, at the moment, AGARD, which although it had military sponsorship was really an international learned society; they had the more restricted conferences such as the joint Anglo-American Aeronautical Conference, and the more specialised international conferences on applied mechanics and so on, all of which were a great drain on the time of aeronautical engineers and scientists. He, for one, felt quite strongly that the various national aeronautical societies should get together to consider the rationalisation of this international position. He would very much like to hear Professor van der Maas' views on this situation.

Boundary layer control was a subject of great scientific interest and the experimental methods were always, he thought, quite impressively elegant and it was fascinating to see some of the methods which had been used in the work in Holland. Yet, he was wondering whether these low drag or high lift properties which one could get with suction and so on were going to be achieved in a practicable aeroplane. He wondered whether the Dutch considered any of these methods when the initial assessment of the Fokker Friendship was being made. Did Professor van der Maas feel that it would be possible to build a practicable aeroplane not vulnerable to flies or not liable to fill itself up with rain water?

Finally, on the wind tunnels he thought the Dutch had made a very wise choice. In particular, he thought that the large transonic tunnel would be exceedingly useful, especially as its speed range covered a region which was now coming very close, even in the civil field. He saw the tunnel when he was recently at N.L.L. and he was glad to hear that it was progressing so well. They all wished them the best of luck in its operation. On a point of detail, the choice of obsolescent ships' boilers and generators was one which he appreciated. It was their own experience, however, that, in general, it was more economic to buy power than to generate it oneself. They had at various times used, for instance, banks of jet engines to provide air or suction and so on, but they found that the labour in running these prime movers had been so high that they had always been glad to buy it from the Central Electricity Board. He hoped that they would not find that those were a great drain on their available effort. His question on

wind tunnels, however, really concerned the projected blow-down supersonic tunnel. He was intrigued by the use of the four heat exchangers inside the pressure vessel because this seemed, in his experience at least, rather a new arrangement. He could quite see some of the possible mechanical advantages, but he imagined the heat transfer calculation was rather involved and he wondered whether Professor van der Maas could tell them something about the philosophy behind this choice.

PROFESSOR VAN DER MAAS: He thanked Dr. Cawood for the tribute he had paid to the Netherlands and to the Dutch organisations responsible for aeronautical research.

The choice of the Dart engines for the Fokker F.27 had been made at a time when the engine was not yet developed to the stage necessary for the F.27 design. The choice had been made with confidence based on the good reputation of Rolls-Royce, fully confirmed by the Dart's performance.

The problem of choosing which subjects to investigate was a difficult one, bearing in mind the limited capacity available. The tendency of the research programme to become too extensive had to be checked continuously. About a year and a half ago the organisation had been changed in so far that the original Scientific Committee of the N.L.L. had been dissolved and a new Scientific Advisory Council installed—under the chairmanship of Professor Koiter—which advised both the board of the N.L.L. and the Aircraft Development Board (N.I.V.). The latter already had some advisory groups for various fields of subjects and these had been incorporated as sub-committees of the new Scientific Advisory Council. It was hoped that in this way a good co-ordination between the research and the development programmes would be achieved.

Regarding the future of aeronautical co-operation, one could consider both the exchange of information in international conferences, as Dr. Cawood had mentioned, and co-operation in aeronautical activities as a whole. As far as aeronautical conferences were concerned, there was AGARD, a NATO agency not only meant for organising conferences but also to foster research exchange within NATO, the AICMA Aeronautical Congress, the Anglo-American Conferences, and others. How should these be arranged in future? All combined into one big conference? He was not in favour of putting aside things that had grown historically, but would rather build up on the historical foundations and adapt them to the changing situation. It would be useful for the existing bodies to get together and discuss arrangements which would keep the number of conferences within acceptable limits in such a way that those countries which took a great interest in aviation could take part in a frequent exchange of opinions.

Concerning aeronautical co-operation in general, he held the opinion that it was necessary for Western Europe—including the U.K.—to work together as much as possible. The idea of international co-operation was attractive to most research workers, who for so great a part of their work relied on data and theories supplied by other research establishments. Research was, therefore, frequently considered to be a good starting point for co-operation. One should never forget, however, that applied research was not a goal in itself, but that most research was directed towards development to be followed by production. To achieve tangible results it would, therefore, be necessary to co-operate in development work in the first place.

Perhaps it was optimistic to start investigations on boundary layer control in 1955. Several countries had gone into this problem quite extensively and he recalled that Professor Melvill Jones said in a Royal Aeronautical Society lecture many years ago "the problem has been solved fundamentally, so you go ahead and try to make it a practical proposition." Since then, the progress towards practical results had been very slow. The fundamental possibilities were, however, attractive and besides, research in this field was very instructive to students. It was still hoped that the research started might lead to some practical results, either positive or negative.

The choice of power supply for the new wind tunnels had been difficult indeed. In the 1949-1952 period, when actual construction work had been stopped due to lack of funds, the question had again been investigated whether it would be wise to complete the power house built around the generators obtained from war surplus ships, or to buy the electricity from the city. The latter possibility, however, was once again rejected as it would be too costly, put restrictions on operation in peak hours, and so on. He agreed with Dr. Cawood that the operation of the power house put a heavy burden on the N.L.L., which aimed at research work and not producing power. The general policy was to abstain from any work not directly needed for research or development but in this case it was considered necessary to make an exception. What little experience there was in the operation of the power house—completed last year—had been satisfactory.

The heat-regenerators in the projected supersonic wind tunnel plant were Dr. Erdmann's idea. He came to the conclusion that the U.S. system of putting cans in the large pressure storage vessel was not quite satisfactory. He estimated the speed distribution and found that at many places the speeds were quite low, giving a bad heat transfer, which was proportional to density times speed. He thereupon conceived the idea of forcing air through regenerators placed in bulkheads in the pressure vessel, which left only part of the cross section open in order to increase the speed. These regenerators consisted of steel sheets, 2 mm. (around 0·08 in.) thick and spaced 2 mm. apart. There were four regenerators, the cross section of each being proportional to the volume of air behind it, so the air speed was equal in all regenerators. The calculated efficiency was about 50 per cent, which was considerably higher than in the "can" system. It had been estimated that about 600 tons of tin cans would have been required to do the same job as the presently designed regenerators, weighing 60 tons in total. A report on this subject was being prepared and would probably be published within a few months time.

G. W. H. GARDNER (Director, Royal Aircraft Establishment, *Fellow*): He was sure that everyone who had heard Professor van der Maas' most entertaining lecture would not be content to leave it at that but would wish to read the paper.

He found the reading of the paper most entertaining and was struck by the point that Dr. Cawood had already mentioned that the N.L.L. seemed to be covering a great deal of ground with remarkably small resources. One was tempted to say that never had so much been performed by so few in such a short time with so little money. One appreciated the extreme difficulty which N.L.L. must have faced in deciding what the content of the programme should be. Professor van der Maas had told of the Scientific Advisory Committee which, no doubt, helped the selection process and dealt adequately with the disgruntled customers whose needs were not satisfied. But he would be most interested to hear something about the Board which directed the N.L.L. The words which Professor van der Maas used in his paper were that the Institute was directed by a Board. He understood him to say that this Board was in turn advised by the Scientific Advisory Committee. He would like to know more about the functions of this Board and how satisfactory the organisation was.

He noticed in reading the paper a point mentioned in connection with the development of the F.27, namely that in the course of some tests aimed at developing a clear view windscreen an attempt had been made to simulate rain conditions. They had always found this very difficult and wondered if Professor van der Maas could say a few words about the method and whether he considered it to be quite satisfactory.

The only other point which he would like to mention, was that it was obvious from the paper and listening to Professor van der Maas that in Holland quite excellent work had been done in solving the measuring instrument problems, and in applying these very excellent instruments to measurements both in the laboratory and in flight. Some of the methods were most elegant and interesting and he would like to congratulate their Dutch friends on their achievements in this direction.

PROFESSOR VAN DER MAAS: He elaborated on his reply to Dr. Cawood concerning the width of the field of research covered by the N.L.L. He indicated that it was essential to cover a certain number of subjects even for a small laboratory like the N.L.L. in order to fulfil its task towards the Dutch Aircraft Industry and operators, which needed its advice on widely varying subjects. The only solution to keep pace with the rapid development was to have sufficient technical staff.

The Board which directed the N.L.L. consisted of representatives from the Ministries concerned—Transport, Economic Affairs, Education, Navy, Air Force, Treasury—and some others, such as K.L.M., the Aircraft Industry and the organisation for Applied Scientific Research (T.N.O.). One or two other qualified people in aviation had also been appointed members. Furthermore, the President of the Scientific Advisory Council attended the meetings of the Board. The Minister of Transport was responsible to the Government for the funds supplied to N.L.L., which appeared on his budget. He also appointed the president of the Board. The Development Board (N.I.V.) was similarly constructed and this also came under the financial responsibility of the Minister of Transport, to whom the programme for development projects had to be submitted. The Government representatives on these Boards were considered to be of such rank in the Ministries that they would stand for what they voted for. Both Boards assembled once every six to eight weeks.

A programme for research work was drafted yearly in October by the Director of the N.L.L. and submitted to the Board, which passed it on to the Scientific Advisory Council for comments. This Council, after having discussed the subjects in detail in its subcommittees, prepared a report to the Board which then assembled to finalise the programme. Besides this, the Aircraft Development Board submitted proposals for research contracts—partly derived from the aforementioned programme, partly from questions arisen in the course of development work—to the Council for technical advice. Finally, the Scientific Advisory Council had a task similar to that of the British Aeronautical Research Council in critically judging the publications of the N.L.L. in order to assure that they were, and continued to be, of a high level. This, of course, held for all work—not only for that part which was published —and it was the purpose of having a Scientific Advisory Council composed of members of the highest scientific qualifications available in the country to guarantee the level of the scientific work.

He undertook to send Dr. Gardner a report on the technical details on the rain simulation method used in the F.27 wind tunnel tests. He passed Dr. Gardner's tribute to the instrumentation of the N.L.L. tests on to Mr. van Oosterom, head of the flight testing section of the N.L.L., who was present at the lecture.

E. T. JONES: He was sure they would all wish him to allow this discussion to carry on as it was most interesting, but having a clock in front of him and the well-being of the lecturer in mind, he did not think it would be fair of them to tax him too much. Having to speak impromptu in discussion in a language not his own, even though he was adept in English, could be quite a trial, so he must now close this interesting discussion.

He did not think that he could add much to the remarks of Mr. Cawood and Mr. Gardner. They had clearly indicated that they had all had great pleasure in listening to Professor van der Maas, and he was glad that they had mentioned the very great contribution the Netherlands had made in the world of aeronautics. He thanked Professor van der Maas very much for coming and giving the lecture and hoped that they would see him addressing them again in the near future.

DR. S. NEUMARK (Royal Aircraft Establishment, *Fellow*) *contributed*: He would like to assure Professor van der Maas that a great many members of the Society (many more than were able to attend the lecture in this era of petrol restrictions) were deeply interested in Netherlands' aeronautical research and in this lecture in particular. Numerous members of the British research teams found a lot of food for thought in various valuable papers originating in N.L.L. and in the Technological University of Delft. In many cases they found confirmation of their own results, in others had to re-appraise their assumptions in the light of original Netherlands concepts and critical outlook, and often were grateful recipients of great and inspiring discoveries and solutions produced by the country which, although small in territory, was not a small power in the world of scientific achievement. For all those, Professor van der Maas' lecture was a welcome general review of these lasting resources acquired by patient efforts of many gifted workers; and, from this point of view, the imposing list of references at the end of the lecture was of particular value. This carefully sifted list comprised only the cream of the grand total, and only a few in the aeronautical world could not find great help and source of new ideas for their own field in these excellent papers.

He then commented on some outstanding examples mentioned briefly by the lecturer (partly known already in this country, and partly recent acquisition), belonging to the field of aerodynamics and stability: —

(1) *Half-model technique* (Section 2.2.1, Figs. 5, 6). This method was in general (and sometimes uncritical) use everywhere, and it was enlightening to see the comparison of results obtained by using a plain symmetrical model and the same model provided with a separating disc in the symmetry plane. It had usually been assumed that there would be only a negligible difference due to the disc boundary layer, but this was shown to be not quite so. The principles of symmetry and mirror reflection seemed to be somewhat in the wrong. Should the explanation not be sought in the old knowledge of von Kármán's vortex street? That was one well known example, in which full geometrical symmetry resulted in a non-symmetrical velocity and pressure field. Now, the model in Fig. 5 having a large sweepback and increasing incidence, an increasing flow separation with shed vortices seemed unavoidable, and this would occur in a different way in the two cases. The increase of differences with incidence pointed in this direction. One simple check would be to try a half-disc (only in front of the model), another one to use an unswept wing—in both cases the difference should practically disappear.

(2) *Experimental check of theoretical values of oscillatory stability derivatives* and the study of the effect of discrepancies on flutter critical speed, on such a vast scale (first part of Section 2.2.3, Figs. 22-24) was novel and important. Fig. 24 was a striking lesson for many consumers of derivatives who often asked for "just rough but quick estimates" and claimed that widely different aerodynamic derivatives would lead to "almost the same critical speed!" In Fig. 24, the structural damping factor g of positive and *negative* values was considered, although it was known that at least this particular damping never became negative. Was the reason of this "excursion into negative" to show the imaginary safety margin for the (wrongly obtained by use of over-optimistic theoretical derivatives) stability?

(3) *Timman's brilliant theoretical discovery in the field of two-dimensional oscillating derivatives in high subsonic range*. This beautiful analytical solution, by means of Mathieu functions, ranked high in aerodynamic theory, and was something of a shock for many predecessors who, despairing of the possibility of an algebraic solution, went the defeatist way of relying on brute computing force (the way which threatened to become a time-honoured escapist way in many parts, thanks to the monstrous development of electronic brains!). The solution was severely attacked because of some initial discrepancies between old and new arithmetical results but, as often happened, the errors were found to be computational only, and the new theory emerged victorious, to the great delight of "algebraists."

(4) *Theoretical calculations of three-dimensional oscillatory derivatives in high subsonic range* had been a hard problem indeed, and one of the many stumbling-blocks for designers of modern high-speed aeroplanes in all countries with great aeronautical ambitions and resources. It was inspiring news to hear that Netherlands research had made a vigorous progress also in this field (*cf.* Section 2.2.7, Fig. 33). The latter figure had caused some slight commotion among a group of British specialists, as it seemed to be at variance with their results. However, a more careful examination led to the conclusion that the only culprit was NOTATION! It appeared that the C_{m_q} of Fig. 33 (and 32) was not, as originally assumed, the equivalent of the British m_q, but rather that of the British stability derivative $m_{\dot{\theta}}$ (or flutter derivative m_a). Now, it was known (*cf.* R. & M. 2903) that

$$m_{\dot{\theta}} = m_q + m_{\dot{w}}, \quad . \quad . \quad . \quad (1)$$

where m_q was the well-behaved derivative (of an essentially "steady" sort), with a persistent small minimum near the mid-chord station, while $m_{\dot{w}}$ was the guilty misbehaving monster, as many a designer came to learn to his cost. The N.L.L. C_{m_q} corresponded *exactly* to the American expression:

$$C_{m_q} + C_{m_{\dot{\alpha}}}, \quad . \quad . \quad (2)$$

but it was *twice* bigger than (1). The nasty $m_{\dot{w}}$ (or $C_{m_{\dot{\alpha}}}$) shifted the position of minimum rotary derivatives so much to the front in the high subsonic range, and would also, for even larger aspect ratios and/or Mach numbers, make the minimum itself to change sign. With this interpretation in mind, the full curve of Fig. 33 found its comfortable place in the family of our curves, but he would be glad to have the lecturer's confirmation.

It might be mentioned that these facts had significant implications in design. If a *large unswept tail on a short arm* were used for an aeroplane with c.g. positioned near the minimum of the resultant rotary

derivative of Fig. 34, then it would contribute nothing, or negatively, to the aeroplane damping in pitch.

PROFESSOR VAN DER MAAS: He thanked Dr. Neumark for the appreciation which had been given to the work of those engaged in aeronautical research in the Netherlands.

He welcomed the technical comments of the contributor which were stimulating and provided many points for further thought. As to the particular points which had been raised he would like to comment as follows:

1. *Half-model technique:* The suggested explanation of the rather large effect of the wall on a swept half-model was certainly worth checking in the further experiments which would be made in this respect. In the discussions held at the N.L.L. on this subject attention had so far been focused on secondary flow phenomena rather than on the effect of unsymmetrical vorticity.

2. *Experimental check of theoretical values of oscillatory stability derivatives:* As the calculations yielded both positive and negative values of the damping factor the negative values had been included in Fig. 24 in order to facilitate the fairing of the curves and so give a more complete picture than could be obtained if only the positive values had been plotted.

4. *Theoretical calculations of three-dimensional oscillatory derivatives in high subsonic range:* Dr. Neumark was right in supposing that the notation in Figs. 32 and 33 had been based on the American procedure. This also accounted for the factor 2 in comparison with the British coefficients which were based on the full chord/length instead of the half chord used by the N.L.L. The C_{m_q} indeed corresponded to the $C_{m_q}+C_{m_{\dot{\alpha}}}$, in the American nomenclature.

The Packaging of Electronic Equipment

Equipment, Design and Methods of Shock Protection

by

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SUMMARY:— The problems involved in the packaging of Service radar equipment are reviewed. Information on shock testing techniques, instrumentation and a design procedure for cushioning are given, together with some examples of current packaging methods used by the Ministry of Supply's Radar Research Establishment, Malvern, Worcs. The paper is based on a lecture given to the Royal Aeronautical Society, Gloucester and Cheltenham Branch in December 1954.

1. Introduction

In the past five years considerable progress has been achieved in the protection of delicate military equipment by suitable packaging techniques. The two main problems are:—

(*a*) Moisture protection, when in transit and stored under adverse climatic conditions.

(*b*) Protection from mechanical shocks and vibration in transit.

With regard to moisture protection, it is necessary to safeguard against corrosion of mechanical assemblies and to prevent deterioration in the electrical insulation of the circuits. This can be achieved satisfactorily by the use of preservation treatments and/or moisture vapour barriers, such as metal foil laminate, Polythene film, or sealed metal containers, in conjunction with a suitable quantity of desiccant. These techniques are covered by Specification DEF 1234[1] and associated specifications, and have been found to be very effective in Service use.

The design of package cushioning to protect equipment from mechanical shock during transit and handling is a more complex problem. Although the subject has received a good deal of study, particularly in the United States of America by Dr. R. E. Mindlin[2] and others, there is yet no complete theoretical treatment. The equations by Mindlin have not been adopted by packaging designers to any great extent, primarily because they are too formidable for day-to-day applications and, secondly, they require knowledge of the stress/strain characteristics for each cushioning material; very little data on this has so far been published in the United Kingdom.

To design a cushioned package satisfactorily, consideration must be given to the three main factors involved:—

(*a*) A knowledge of the shock and vibration conditions to which a packaged equipment will be subjected in transit and handling.

(*b*) The breakage characteristics of the equipment to be packaged, embracing the maximum permissible accelerations, deflections and resonant frequencies of the various assemblies or components of the equipment.

(*c*) Data on the shock absorption, load supporting properties and stability of cushioning materials.

Received October 1956.

2. Transit and Handling Shock and Vibration Conditions

There are many types of transport which can be used for the movement of packaged equipment, and each presents its own particular problems and range of shock and vibration conditions.

Packages should be designed so that the cargo is protected when transported by road, rail, sea or air, and should meet satisfactorily the movement hazards involved in loading and unloading by slings, cranes, fork lift trucks, man-handling and so on. A brief summary of the environmental conditions which may arise is given below.

VEHICLES

(*a*) *Transient Shocks*

Railway Transportation. During transit by rail sudden changes of direction, such as those experienced during shunting operations, impose considerable mechanical shock. In shunting, impact velocities up to 10 feet per second with a deceleration of up to 30*g* may be produced. The dominant frequency in such conditions may be about 100 c/s with a building-up period of about 20 milliseconds.

Road transportation. Shocks during normal road transport on paved highways are generally small. Military vehicles may be driven over rough roads, giving rise to accelerations of 2·5*g*. Shunting operations and sudden bumps of cross country tracks and rough road journeys can impose severe transient shock responses as high as 20*g*.

(*b*) *Vibration*

Railway transportation. During a journey, the beat of the wheel on rail joints and similar running shocks may produce continuous vibrations in the range 2-3 c/s at amplitudes up to $\pm 1\frac{1}{2}$ in.

Road transportation. Road surfaces may set up vibrations within the frequency range 1-15 c/s with acceleration of 5*g* as a maximum.

SHIPS

(*a*) *Transient Shocks*

If packages are properly stowed aboard ship, cargos do not experience shock of any significance under normal conditions.

(*b*) *Vibrations*

Vibrations on ships are primarily excited by the engines and propeller, but also by other means such as electrical equipment and winches.

The degree of vibration varies greatly with the size of ship, type of engine, etc.; vibration is generally in the range 5-20 c/s with amplitudes less than $\pm 0{\cdot}03$ in. These conditions are likely to be sustained for long periods.

AIRCRAFT

(*a*) *Transient Shocks*

While in flight, the forces imposed on packaged equipment are unlikely to be serious, but occasions may arise during manoeuvring, or during passage through turbulent conditions, when loadings up to a maximum of 3*g* for several seconds can occur. In landing, taxying and take-off, shock levels may reach values of 4*g*. The shocks sustained during handling and loading will be of greater magnitude—up to 12*g*. For parachute drops, the velocity at contact with the ground is equivalent to a 12-15 ft. free drop.

(*b*) *Vibration*

In the central regions of the aircraft, the vibration levels range from 10-500 c/s. At the lower end of the frequency scale the amplitudes are about $\pm 0{\cdot}008$ in.

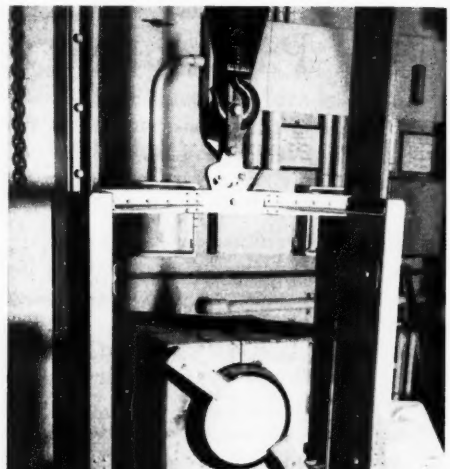

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FIGURE 2. View of ram.

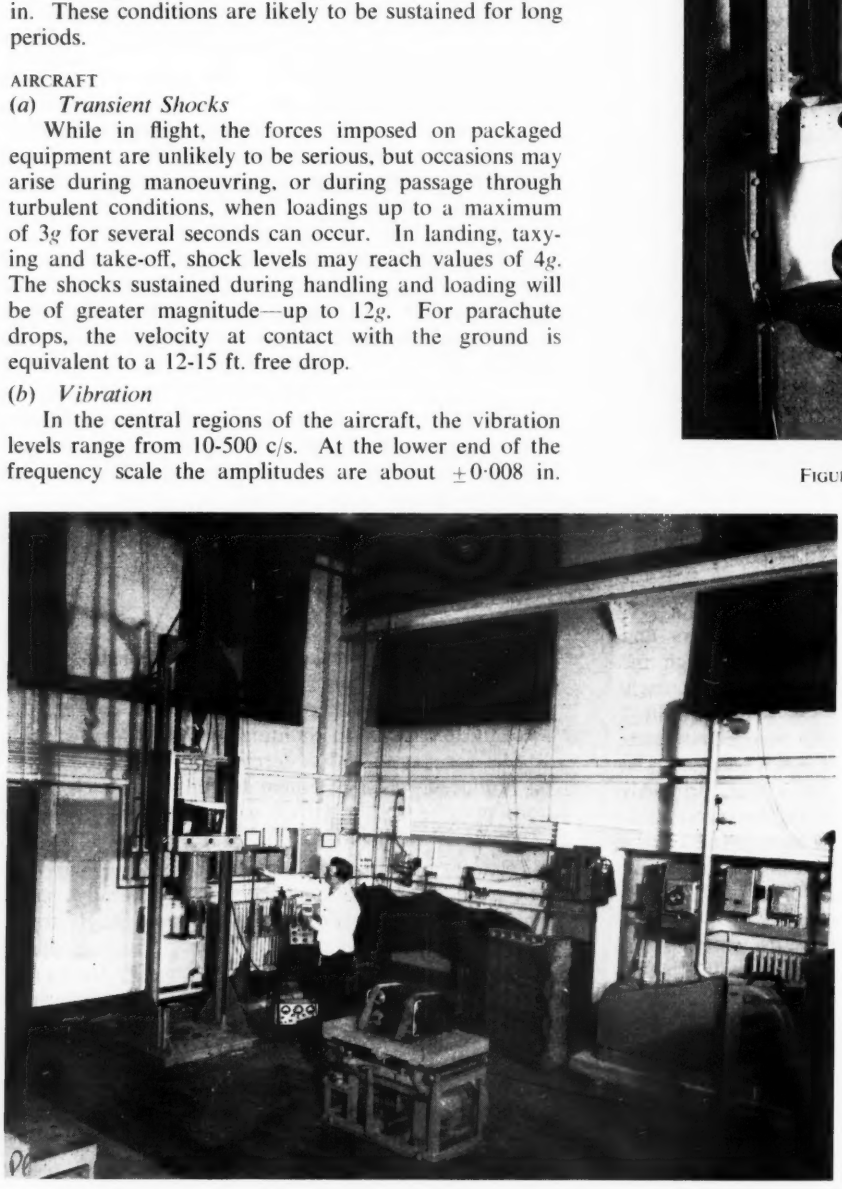

FIGURE 1. General view of drop test machine.

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STACKING LOADS

Packages in a depot or maintenance unit may be stacked to a height of 20 feet. Crushing loads of one ton/ft.^{2} may be encountered during sea transport.

TRANSIT HANDLING AND ROUGH USAGE

During loading and unloading of packaged equipment from vehicles, ships or aircraft, shocks may be experienced equivalent to a free drop from a height of four or five feet on to concrete. The damage which may result depends to a great extent on the amount of cushioning in the packaging and the strength of the container. Experience has shown that drop hazards and mishandling are greater with lighter packages, mechanical aids being used to move the heavier loads; even with these loads, however, final positioning may be by hand and the package may well be tipped from one side to another. Trials made with the different methods of transportation show that the major shocks are invariably caused by rough handling and therefore, the drop test is chosen as the main factor in test schedules to simulate handling operations.

Instrumented drop tests on electronic equipment show that large values of deceleration may be sustained at component mountings and sub-assembly locations. If a typical airborne radar unit without packaging were dropped from a height of four feet on to concrete, the item would sustain a shock of up to approximately 1,000g with a duration time of one millisecond.

SIMULATION OF SERVICE HAZARDS

A brief schedule of tests for packages is contained in Part II (Section 7 of the Specification DEF.1234). It should be noted that this schedule is intended only for testing packages embodying approved packaging materials and techniques. Additional tests based on simulation of the hazards already reviewed will be required to meet special conditions, or when entirely new packaging techniques are employed.

3. Equipment Fragility

For some items, such as simple brackets, channel and cantilever structures, the "safe" deceleration figure (or fragility factor) can be determined by calculation. Most electronic assemblies are complex structures and it is not known beforehand which are the most fragile elements. It will then be necessary to determine the breakage characteristics of the equipment by shock testing the item to reveal the weakest part of the assembly or failure of a specific component part. A shock test is also more accurate because ductile structural materials will often endure many higher deflections and accelerations under transient shock conditions than steady state loads.

It is necessary that the waveform of the deceleration loadings imposed during the tests should be similar to that which the packaged equipment would actually encounter under rough handling conditions, and a deceleration testing machine has been designed at R.R.E. which produces a suitable waveform for this purpose.

IMPACT TESTING MACHINE

The machine consists of a metal carriage approximately two ft. square on which the equipment or component to be tested is mounted. The table is free to move up and down between two vertical steel posts and is guided on these posts by eight steel rollers. The table is raised by means of a hand or power-operated hoist. The wire rope which is used for raising the table passes over pulleys mounted at the top of the framework and down to the winch. Connection between rope and carriage is by means of a magnetically-operated bomb release.

Mounted on the underside of the table is a pneumatic ram which acts as the retardation pad or cushioning. The ram consists of a cylinder and piston, air being pumped in or extracted through a Schrader valve. The intensity of the shock can be varied over a wide range; the greater the amount of air within the cylinder, the better the cushioning and the smaller the shock. Fig. 1 is a general view of the machine. Fig. 2 shows the pneumatic ram with a cathode ray tube on the table ready for testing.

The pneumatic ram will provide a peak applied acceleration in the range of 5 to 90g with duration times in the range 10-50 milliseconds with variation of drop heights from one ft. up to 4 ft. 6 in. and table loads up to 100 lb., as shown by the calibration curves.

Typical acceleration waveforms are shown in Fig. 3.

To operate the machine, the equipment is mounted

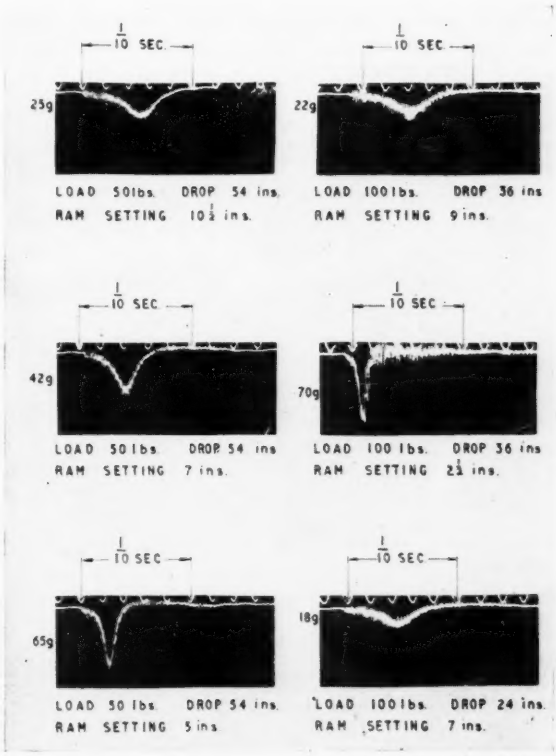

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FIGURE 3. Acceleration waveforms.

on the table which is raised to the necessary height. The ram is set up to give a maximum cushioning, that is, to reduce the peak shock to, say, 10*g*.

The table is released and falls on to the steel plate; the equipment is then functionally checked and inspected for mechanical failure. This procedure is repeated with gradually increasing shock intensities, until a level is reached which will cause some mechanical or electrical failure. This test is performed in each of the two directions of the three main axes. Having obtained the shock level, or fragility factor, for the equipment, the structure can either be modified to improve its impact strength if this is practicable, or this level can be used as the design figure for calculation of the required amount of cushioning in the packaging of the equipment.

EXPERIENCE WITH THE IMPACT TESTER

Experience in testing a considerable number of equipment assemblies, cathode ray tubes, meters, etc., has shown the following general points:—

(*a*) It is usually the mechanical structure of radar assemblies which shows the first signs of damage. Components, valves or meters rarely fail before the structure.

(*b*) Well designed chassis structures rarely failed to withstand shocks (of the nature provided by this machine) of 50*g*.

(*c*) For items involving glass sealing techniques, *e.g.* valves, magnetrons, a number of specimens, 10 or more if possible, should be used for fragility assessment. Fragility scatters of from 25-100*g* have been recorded on otherwise identical samples in this class.

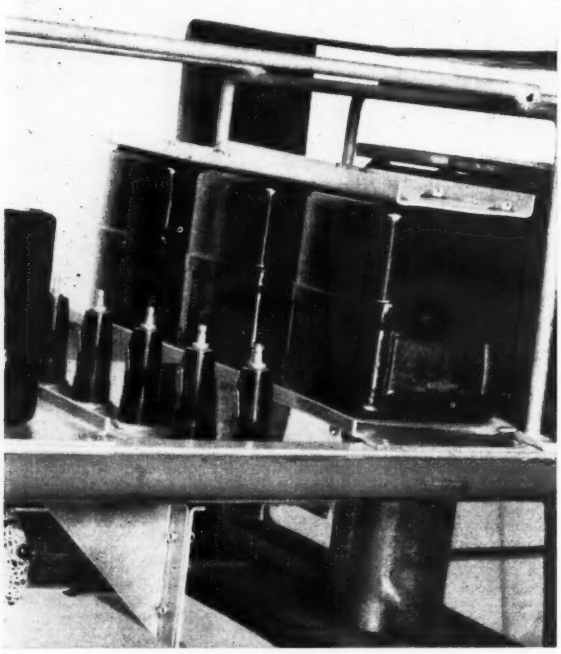

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FIGURE 4. Ground radar sub-chassis.

Figure 4 shows a typical ground radar sub-chassis supporting several heavy transformers. Slight buckling of the aluminium mounting tray occurred at a peak shock value of 43*g*.

Figure 2 shows the machine set up for tests on a cathode ray tube, VCRX432. A series of tests were made to establish the minimum shock required to cause permanent deformation of the gun assembly. The glass envelope was enclosed in a split wooden block and about half an inch clearance between the wood and glass was allowed all round. This gap was filled with beeswax to accommodate dimensional differences in the sample tubes used for the assessment. No measurable permanent deflection was recorded when the tube was subjected to shocks (in 3 planes) of up to 100*g* peak value. The fragility assessment tests in this instance included operating the cathode ray tube and measuring the spot deflection on the face of the cathode ray tube on impact. The results of a drop test on an item of field test gear are shown in Fig. 5. The aluminium chassis distortion was due to a shock of 75*g*; the equipment was still electrically satisfactory.

It should be noted by equipment designers that designing cushioning in the package for 40*g* protection is a reasonable proposition but, if the fragility falls substantially below this figure (say, 25*g*) the cost of the packaging and the difficulty of providing the necessary protection is very considerable. Care should therefore be taken to provide heavy components, such as transformers, with adequate strength in the fixing lugs and retaining bolts. This can generally be done without adding to the bulk or weight of the equipment.

VIBRATION

Although deceleration shocks of the type simulated above are usually the main causes of damage to equipment in transit, prolonged forced vibration can also cause important fatigue effects and damage in packaged equipment if proper vibration isolation is not provided. It is important, therefore, to determine the resonant frequencies of the structure and sub-assemblies of the equipment and of the cushioned package.

Vibrations will be transmitted through the packaging cushioning in varying degrees and will produce accelerations at the cargo equal to, less than, or greater than, the external forcing acceleration.

Most airborne radar equipments are complex structures which have many critical resonant frequencies. Those frequencies which are in the transportation range will have to be considered in the design of the cushioning, also the type of closures and style of construction of the outer case of the package.

If the applied vibration range of the transport vehicle excites a resonance in the structure of the cargo, or the cushioning system of the packaging, the severity of the vibration experienced will be considerably increased.

It is important, therefore, with packaged equipment, especially if it incorporates new techniques of cushioning, to make vibration tests before the design is approved.

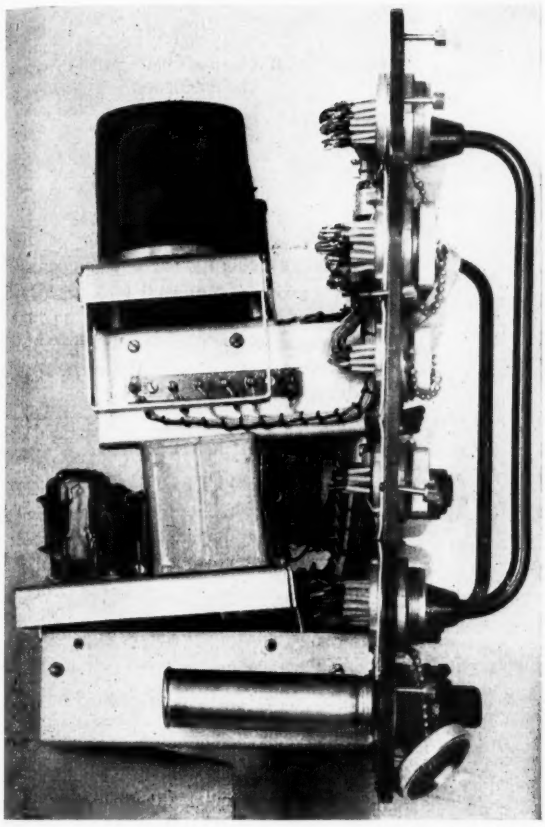

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FIGURE 5. Damage due to shock of 75g.

4. General Properties of Cushioning Materials

Apart from the important aspects of cost and availability, the two main technical aspects of a cushioning material or system are:—

(*a*) General chemical and physical properties—*e.g.* stability under wide variations of temperature and in the presence of moisture; good ageing properties; ease of application.

(*b*) Shock absorption and vibration isolation—*e.g.* efficient dynamic load/compression performance and damping characteristics; good fatigue properties under successive cycles of compression.

LOAD COMPRESSION PERFORMANCE AND EFFICIENCY

The amount of material required for cushioning a particular cargo, and hence the bulk of the package, is mainly dependent on the impact energy absorption efficiency of the cushioning, *i.e.* the shape of the compression performance curve for the material.

The shapes of the compression performance curves for some commonly used cushioning materials and systems are shown in Fig. 6. The energy absorbed or stored by the material is equal to the area under the curve. Class 1 is the ideal curve but it is not obtainable with any available material. Flexible foamed synthetic rubber-like plastics, such as the fine texture polyurethane materials used under "non-bottoming" conditions, come within Class 2, while the coarse texture types come within Class 3. Tied compression springs such as the "Metpak" are typical of Class 4; normal tension springs are within Class 5. Rubberised hair of high density, bonded wood wool and similar bulk cushioning materials come within Class 6. Medium and low density rubberised hair, expanded rubber and similar materials have a characteristic within Class 7.

At the Radar Research Establishment some tests have been made to evaluate the dynamic characteristics of moulded rubberised hair. The properties of the material are obtained by measuring the deflections and accelerations which result when various weights are dropped from different heights on to pads of the material of various thicknesses and densities.

Curves have been prepared showing the force/deflection characteristics for drops of 12 ins., 24 ins. and 36 ins, together with the curves of the energy/deflection and the static loading characteristics. The dynamic force was obtained by multiplying the peak acceleration by the weight of the loaded table. The energy absorbed for each drop was obtained by assuming it to be equal to the potential energy of the cradle.

From the results so far, it appears that the dynamic characteristics are markedly different from the materials of different densities. With the heavier density material, the pneumatic effect is thought to be greater. The force exerted by the material of heavier density for a given deflection depends on the height of drop, while with the lighter grade the force is almost independent of drop height. This is because the greater the height of drop, the greater is the velocity of impact, thus requiring a more rapid dispersal of the air within the pad. With a high density material, although a smaller volume of air is contained within the pad, restriction to its movement

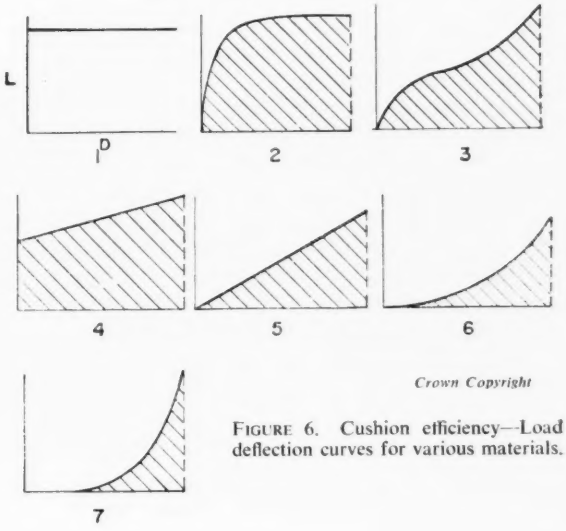

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FIGURE 6. Cushion efficiency—Load deflection curves for various materials.

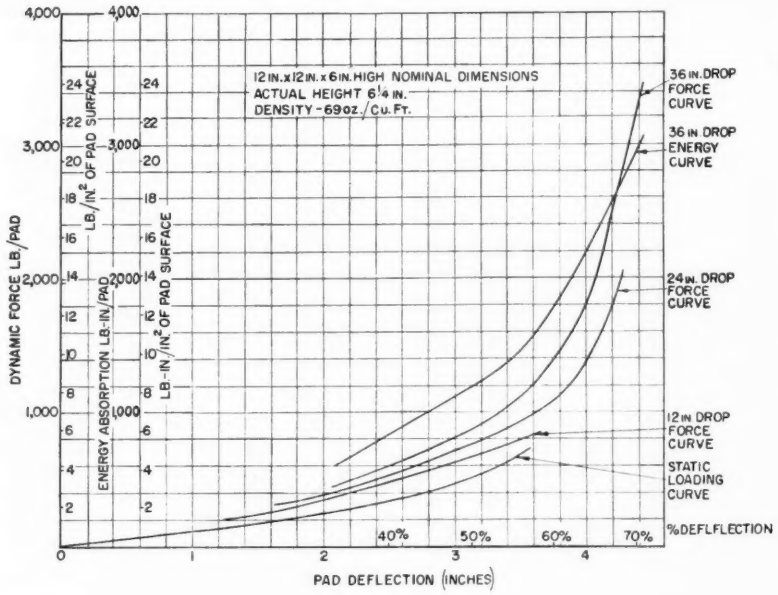

FIGURE 7. Rubberised hair pad—dynamic characteristics.

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would be greater. With light density materials this restriction is negligible.

Consideration of the possible energy absorption and the dynamic force characteristic shows that, at 50 per cent deflection, the lighter density energy absorption is only about half that of a system having a linear characteristic. The heavier density material is much better and, at 60 per cent deflection, it approximates to a linear system (*See* Fig. 7).

The "bottoming" point of the light grade material occurs at some 70 per cent deflection, while the heavier grade "bottoms" at approximately 60 per cent deflection. To work beyond these deflections would mean that the shock applied to a packaged cargo would increase at a rapid rate for a small increase in drop height. It is desirable therefore to work below the "knee" of the curve.

From curves of this type, the shock to which a packaged equipment will be subjected can be calculated for the flat drop condition.

Other aspects on which there is as yet very little data, but which are known to play a significant part in packaging performance, include:—

(*a*) Influence of the package container on the overall shock performance. Some limited experiments indicate that the cushioning has not only to deal with the energy of the cargo but must also cater for the rebound energy of the outer case.

(*b*) The pneumatic effect in the performance of sealed containers and bulk cushioning materials.

(*c*) The shape of bulk cushioning and the effect of cavities and cut-outs in mouldings on shock performance.

(*d*) Effect of corner and edge drops on the behaviour of cushioning materials.

When the overall plan of the package design is decided, a prototype pack is prepared and performance checked by measuring the decelerations at the cargo (or dummy cargo) when the pack is drop tested.

5. Instrumentation in Packaging Investigations

In order to evaluate the dynamic performances of cushioning materials and to obtain the dynamic loadings on the cargo in packages during drop testing, it is necessary to have available a suitable piece of equipment which will give a picture of the deceleration wave-form. R.R.E. in conjunction with Boulton Paul Aircraft Limited, have developed an equipment for this purpose, consisting of the following items:—

(*a*) Accelerometer unit,

(*b*) Release unit,

(*c*) Delay and power unit,

(*d*) Monitor unit (with peak acceleration meter if required).

The complete system is shown in Fig. 8.

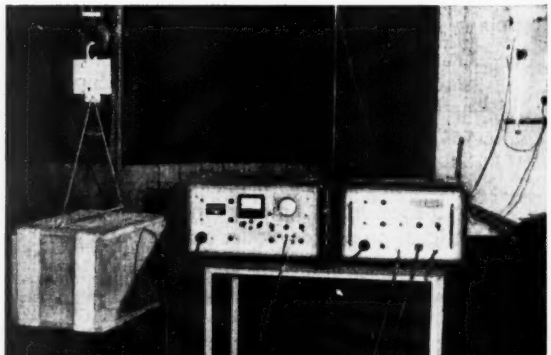

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FIGURE 8. Instrumental set-up for drop tests.

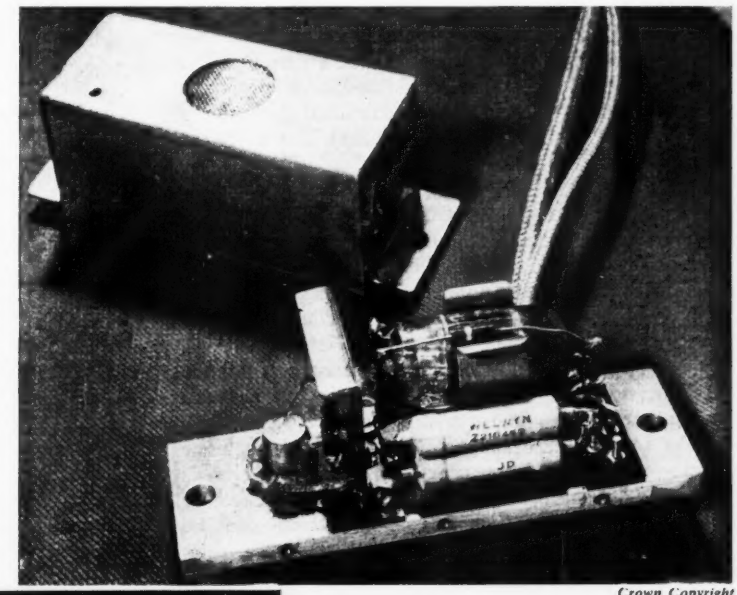

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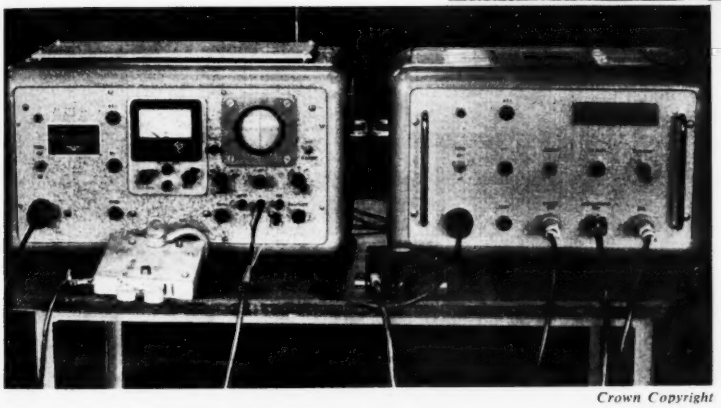
FIGURE 9 (*right*)
Barium titanate accelerometer.

FIGURE 10 (*below*)
Trigger unit and monitor unit.



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the package under test and a single flexible multicore cable is brought away from it.

The complete accelerometer unit weighs six oz. and is approximately 5 in. × 1½ in. × 1¾ in. high.

The maximum acceleration (or deceleration) which can safely be applied to the assembled accelerometer (including valve) is 100*g*. Forces due to slightly greater acceleration do cause a slight drift of the output voltage, but with no loss of sensitivity.

ACCELEROMETER UNIT

The accelerometer itself consists of a small piece of barium titanate cemented to a metal mass. Acceleration and deceleration of the unit will cause a decrease or increase of pressure on the crystal, with consequent generation of a voltage pulse due to the piezoelectric properties of barium titanate. The output from the crystal is fed into a cathode follower valve circuit designed to give a high input impedance. This is essential to prevent the charge leaking away when the rate of change of acceleration is low. The accelerometer and valve are mounted close together in a common base plate to minimise length of connection. Long lengths of connecting cable between these items reduces sensitivity of the accelerometer due to added capacity and, can introduce electrical distortion caused by static charges being developed when the cable is flexed. The valve chosen is robust and free from microphony over the acceleration range. Fig. 9 shows the complete accelerometer unit.

The base plate is fixed in the required position in

RELEASE UNIT

This consists of a standard R.A.F. electro-magnetic bomb release which has been suitably modified. The package is suspended from the jaws of the release. The jaws are opened by an electrical pulse fed from the delay and power unit. Thus the operator can be located at a safe distance from the package being drop tested. Loads up to a maximum of one ton can be carried by the release unit.

DELAY AND POWER UNIT

This unit, which is shown on the right in Fig. 10, provides the power for the cathode follower in the accelerometer unit and a switch to open the release unit jaws.

As already mentioned, a complete picture of acceleration pulse against time is obtained if the output of the accelerometer unit is displayed on a cathode ray tube. For ease of measurement it is important that the peak of the acceleration pulse is always displayed at about the same point on the tube face. To achieve

this, and having regard to the different time intervals which will occur between the release pulse and the impact shock for different drop heights, a variable time delay circuit, with a control calibrated in drop heights (up to 6 ft.) is provided. This ensures that the cathode ray spot starts to move across the screen at the correct instant for any drop height.

MONITOR UNIT AND PEAK READING METER

The accelerometer unit output can be displayed on a standard cathode ray oscilloscope, but it is often advantageous to use a unit specially designed for the purpose, and which makes the whole equipment self-contained. The monitor unit, on the left in Fig. 10, consists of a $2\frac{1}{2}$ in. diameter long persistence cathode ray tube, together with stabilised power supplies and associated circuits. The use of a long persistence tube enables intensity and shape of shock wave form to be quickly assessed. For permanent record, provision is made for attaching a 35 mm. single shot camera. A calibration signal is also available which can be switched in either immediately before, or after, drop test, as required.

For routine checks on standard packages where only the maximum deceleration value is of interest, a meter which shows the peak value directly can be very useful. Facilities are available on the monitor unit to plug in a peak reading meter assembly which is calibrated in "g" units. The incoming signal from the accelerometer is used to charge a capacitor which has a long discharge time constant. The circuit is re-set to zero by a switch on the front panel.

FUTURE DEVELOPMENT

Work is proceeding on a more sensitive barium titanate crystal unit which can be used directly with cable lengths of 12 ft. and avoid the need for the cathode follower stage in the accelerometer unit. This unit will be approximately $\frac{3}{4}$ in. diameter x $1\frac{1}{2}$ in. long and will be of particular value for use with small packages.

A multi-plane accelerometer is also being developed so that a package can be dropped in each plane without the need for re-orientating the accelerometer each time the direction of the drop is changed.

6. Packaging Techniques

Some examples of current packaging techniques for electronic equipment are described.

SMALL ELECTRONIC SPARES

Polythene film is being used extensively for the packaging of resistors, capacitors, and other small electronic spares. Each component is sealed in a 5 mils. thick polythene envelope and ten components are then placed in a further outer polythene envelope—ten such small packs go into a carton to form a bulk issue of 100 components.

Components such as vitreous enamelled wire-wound resistors, which are rather brittle, are packed separately in a polythene envelope inside a wax-dipped

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FIGURE 11. Airborne radar pack.

spirally wound carboard tube. Ten resistors are then arranged in a bundle secured with two rubber bands and placed, together with identification labels, in a polythene envelope of appropriate size. The bundle technique, using a rubber band, can be applied to a wide range of electronic components; it provides a most economic pack and facilitates the insertion of the components into the polythene envelope.

MOULDED RUBBERISED HAIR

For equipment of irregular shape, mouldings of rubberised hair are particularly useful for package cushioning. The material is light, resilient, and can be readily moulded by the use of simple wooden tools.

Several firms manufacture rubberised hair and are approved to the Ministry of Supply Specification UK/AID/919. Examples of its application are:—

(*i*) *Re-usable Packs*:

Under the R.A.F. systems of servicing, squadron workshops will not normally have sufficient trained personnel to repair sub-assemblies of radar equipment. If a fault develops in a unit the defective sub-assembly will be removed and replaced by a new one. The defective sub-assembly will be placed in the packaging provided for the new sub-assembly and returned to Repair Units. Rubberised hair mouldings provide

a convenient reusable packaging and are usually arranged so that the internal surfaces of the top and bottom blocks are moulded to conform with the profile of the sub-assembly. The top block (or lid) is provided with two recesses for locating bags of desiccant.

Where necessary, the moulding can be hinged together with two pieces of canvas and a press stud included on the front face. An alternative arrangement for locating the two mouldings together is to form them in spigot fashion, so that the two halves can be held together without the use of canvas straps. The moisture barrier is provided by a polythene film envelope which is heat-sealed over the outside of the mouldings. The whole assembly is then inserted into a carton of appropriate size.

(ii) Airborne Equipment

The application of rubberised hair for the packaging of a cylindrical airborne transmitter-receiver is shown in Fig. 11. The equipment weighs 30 lb. and has close fitting mouldings of heavy density rubberised hair to enclose the equipment in the smallest possible regular cylindrical shape. A pocket to receive bags of desiccant is left in the moulding covering the front panel. The equipment, together with the conforming mouldings, are enclosed by a 10 mil. thick polythene film bag. The bag is provided "extra" long to permit several sealings, to allow for repeated re-use.

Five inch thick end and girth mouldings of rubberised hair form the main cushioning, and the outer container is a plywood with re-usable metal closures.

The package, including cargo, weighs 70 lb. The cushioning reduces the peak shock to 45*g* on a free drop from a height of 4 ft. 6 in. on to concrete.

(iii) Meters

Figure 12 shows a reusable pack for standard panel mounted meters. The existing Service package is a carton over-wrapped with mouldable material and wax-dipped. In service, removal of the outer M.V. barrier presents some difficulty and in the process the package is most likely to be damaged and rendered unsuitable for the return of the faulty meter.

The new pack uses a metal container with either a slip-on lid or a screw cap closure with conforming mouldings of rubberised hair and a polythene bag for moisture protection.

FIGURE 13 (*above*). Wood-wool pack.
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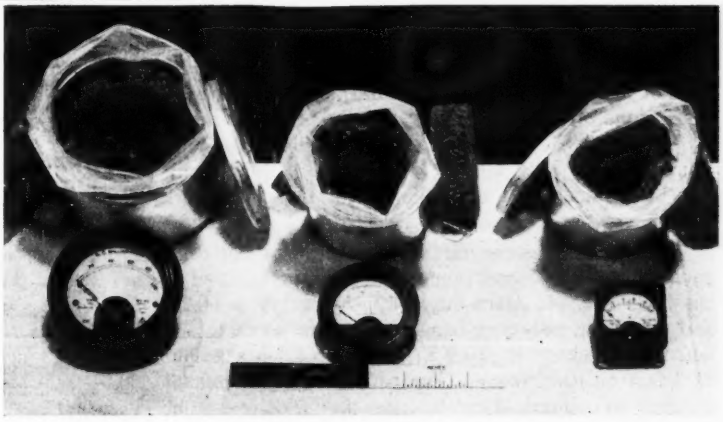

FIGURE 12 (right). Meter packaging.
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MOULDINGS OF WOOD-WOOL

Moulded wood-wool is a useful material for packaging certain types of electronic valves. The moulding is made from shredded wood cuttings, usually of spruce, which are dried and then bonded together with urea formaldehyde under pressure. Fig. 13 shows a magnetron which weighs 17 lb. with its conforming wood-wool moulded pack. The mouldings enable the loads on impact to be spread over the whole surface of the valve and minimise local stresses on the glass boot. It is important that the item be first sealed in a polythene bag before

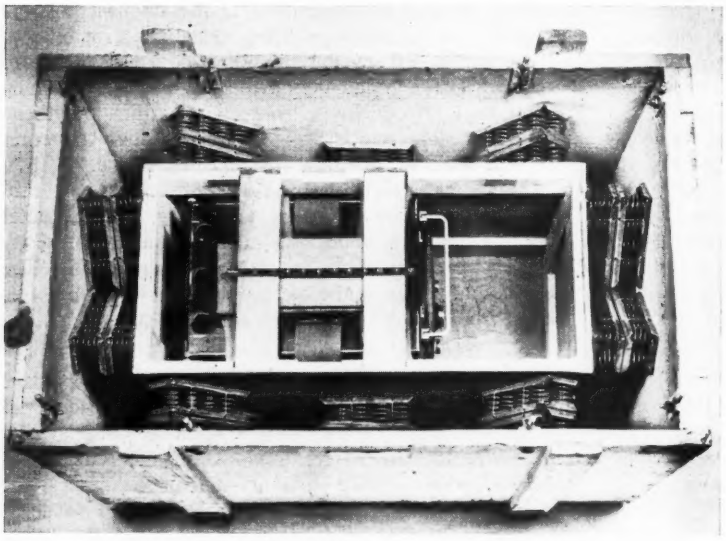

FIGURE 14. Metpak cushioned case.
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insertion in the wood-wool mouldings to prevent any possibility of corrosion.

Wood-wool mouldings are considerably cheaper than other moulded cushioning materials and, although stray curlings break off, this is not a disadvantage for valve packaging. Assembly of the package is very simple and represents a considerable saving in packaging time; the whole arrangement is considerably cheaper than the spring crate type of package which has normally been used for many valves of this type. Low density mouldings have the disadvantage of marked fatigue under repeated impact loadings. Wood-wool mouldings are not recommended for reusable packaging applications, but this is not usually a requirement for valve packaging. For certain applications it may be desirable to have a high density conforming wood-wool moulding as the inner pack, surrounded by shock absorbing pads of low density wood-wool or rubberised hair.

PRE-COMPRESSED SPRING SHOCK ABSORBERS

A range of pre-compressed spring shock absorbers is now available under the registered name of "Metpack". Metpack shock absorbers employ eight compression springs under high compression, which results in the high energy absorption characteristics referred to in Section 4 and provides a material saving in overall dimensions of packaging. The weight of the standard Type 1A unit is 11·5 oz. and the dimensions are 2 in. thick x 6½ in. long x 3 in. wide. The standard unit can be clamped to form a double or triple assembly to give greater protection to the item being packaged.

The shock absorbers are attached to an outer case, usually by wood screws and a typical application is shown in Fig. 14. Here the equipment weight is 60 lb. and the spring pads (two banks) reduce the shock to 30*g* when the package is given in free drop from a height of 3 feet on to concrete. The pads are rather difficult to apply to cylindrical cargoes, and they require a stout outer case because loads are confined to small areas of the case.

7. Conclusions

The satisfactory packaging of delicate electronic equipment is very often a complex problem. These problems can be considerably eased if the designers of equipment incorporate in their equipment features which will assist the packaging design, for example:—

(*i*) Provide mounting of adequate strength for heavy components. Reduce to a minimum projecting assemblies, such as blower motors and flimsy wind funnels.

(*ii*) Provide adequate pick up points or mountings on equipment which can sustain the dynamic loads under impact.

(*iii*) Wherever possible determine the fragility factor of the equipment by a series of tests on a drop test machine. Where necessary, introduce simple modifications to improve the strength factor of assemblies under these conditions.

After a prototype package has been made, instrumented drop tests should be carried out to check that the required protection is being realised by the package.

Attention to the points outlined will facilitate efficient packaging designs and ensure safe shipment of valuable equipment under adverse conditions of handling, transit and store.

ACKNOWLEDGMENTS

The author wishes to thank G. German, A.M.I.Mech.E., for his assistance in the preparation of this paper. All illustrations are Crown Copyright reserved.

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Some Aspects of Three-Dimensional Cavity Flow

by

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(Research Student, Imperial College)

SUMMARY: Some experiments concerned with the wake flows of a number of flat plates of low aspect ratio (Fail, Owen and Eyre[1]) have suggested that for large angles of inclination to the undisturbed stream the wake includes a region of recirculation. The present observations include a detailed study of this region, with particular reference to the wake produced by an equilateral triangular plate, and an attempt is made to explain why the recirculatory flow is found only at angles of incidence greater than 35°. The data includes some wind tunnel measurements of force coefficients, static pressure and mean velocity, and observations of the wake flow made in a smoke tunnel and in a water tunnel.

1. Introduction

Some measurements of mean velocity in the wakes generated by a number of flat plates of low aspect ratio held normal to a stream (by Fail, Owen and Eyre in Ref. 1) gave rise to closed streamlines and demonstrated the existence of a cavity, that is a region inside which recirculation of the fluid occurs. The results of Ref. 1 also included graphs showing the variation of drag coefficient with change in the inclination of the plate to the stream. These graphs all showed a sudden change in drag coefficient at about the same angle of incidence (approximately 35°). Since there was no evidence of the formation of a cavity in the wakes of similar plates at lower angles of incidence (*see*, for example, Ref. 2), it was thought that there might be some connection between this change in drag coefficient and the onset of cavity flow. The present investigation was, therefore, started to determine whether this was so.

An investigation was made of the forces on, and the flow behind, an equilateral triangular plate, with sharp edges. After making some preliminary wind tunnel measurements to confirm that the wake produced was similar to that found by Fail, Owen and Eyre, it was decided that some means of direct visualisation of the flow was needed for a fuller understanding of the cavity flow. Some tests were therefore made to determine the most suitable technique and the most satisfactory results were obtained in a small water tunnel loaned by the Aerodynamic division of the National Physical Laboratory, using polystyrene particles in suspension to indicate particle paths. Since in unsteady flow particle paths are not streamlines, this technique does lead to some confusion in regions where mass transfer due to mixing is high, and for this reason some photographs are included which show the streamlines indicated by some smoke filaments which were introduced into the flow in a small wind tunnel, upstream of the plate, in the central plane of symmetry. Some difficulty was experienced in ensuring that the entire band of filaments lay in this one plane because some of the outer filaments suffered lateral deflections, which carried them out of the focal range of the camera, in the course of their travel past the plate. This may account for a certain fuzziness in some of these smoke traces which might be mistaken for unsteadiness in streamlines which are otherwise only slightly disturbed; it may also account for the apparent crossing of adjacent streamlines in Fig. 16.

At all angles of incidence, except that in which the plate is normal to the undisturbed flow, the wake is complicated by the presence of two trailing vortices and it will be suggested that these are an important factor concerning the non-appearance of the cavity at low angles of incidence, and also concerning the external shape of the cavity. In order to obtain some information about these trailing vortices, a survey of the total head distribution was made in a transverse plane some distance downstream of the plate and also in the transverse plane containing the trailing edge. This last survey was made at two angles of incidence, one well above that at which the cavity was thought first to appear and one below, and gives some indication of how the cavity might form.

Finally the records of particle paths taken from the water tunnel tests provide some opportunity for qualitative study of the flow within the cavity and this will be considered in detail in a later section.

NOTATION

x, y and z	directions of the three Cartesian axes of reference
a	semi-span of the plate
U_0	speed of the free stream in ft./sec.
U	local resultant mean velocity in ft./sec.
α	inclination of the plate to the undisturbed stream
p	local static pressure in lb./ft.^{2}
H	local total head in lb./ft.^{2}
A	ambient static pressure

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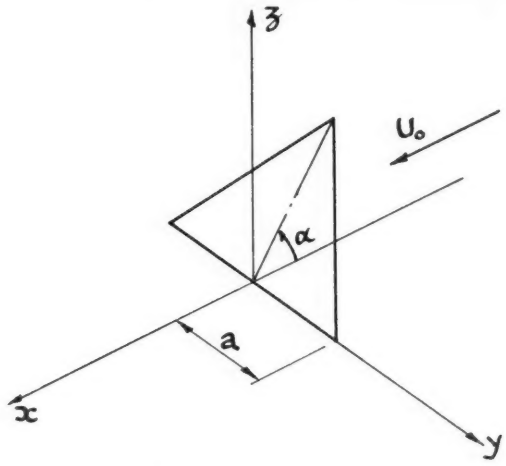


FIGURE 1. Cartesian axes of reference.

$C_p = \frac{p-A}{\frac{1}{2}\rho U_0^2}$ local static pressure coefficient

$C_H = \frac{H-A}{\frac{1}{2}\rho U_0^2}$ local total-head coefficient

C_D, C_L, C_N drag coefficient, lift coefficient and normal force coefficient respectively

2. Experimental Details

2.1. WIND TUNNEL TESTS

These were made in the 5 ft. × 4 ft. low speed wind tunnel in the Dept. of Aeronautics, Imperial College, at a speed of 100 ft./sec. The plate used in all these tests was an equilateral triangle with 8 in. sides, having sharp edges chamfered at 6° and a thickness of 0·1 inch.

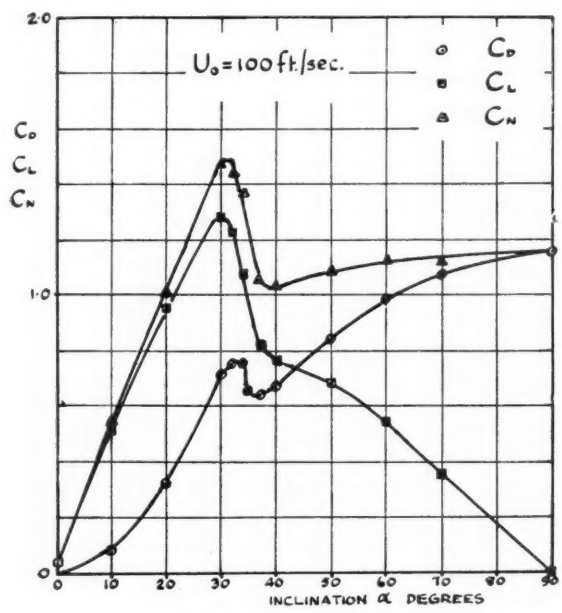


FIGURE 3. Force coefficients.

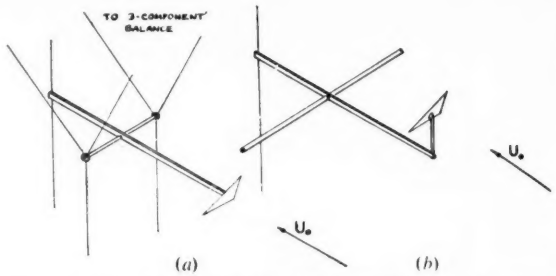


FIGURE 2(*a*). The triangular plate mounted for the balance measurements.

FIGURE 2(*b*). The triangular plate mounted for the mean velocity measurements.

For the measurement of the force coefficients this plate was attached to a long sting which was suspended from the three-component balance in the manner indicated in Fig. 2(*a*).

The resulting force coefficients are plotted in Fig. 3 for angles of incidence from 0° to 90°.

The plate was next attached to the same sting, modified—*see* Fig. 2(*b*)—to give a minimum of interference with the wake flow. A hot-wire anemometer was used to measure resultant mean velocities in the plane $y/a=0$ on the downstream side of the plate, at angles of incidence ranging from 40° to 75°.

In Figs. 4 to 7 these results are presented in the form of contours of constant velocity.

With the same plate held on a simple streamlined stand, a survey of the total head was made in the transverse plane $x/a=6$, at $\alpha=40°$, using a Kiel type shielded total-head tube which was insensitive to angles of yaw less than 35°. Two further surveys were made in the transverse plane $x/a=0$, for angles of incidence of 30° and 50°. Contours of constant total-head coefficient, C_H were then drawn from these surveys and these contours are presented in Figs. 8 and 9.

Finally, using the same support, a disc static pressure probe of the type described by Bryer, Walshe and Garner[3] was used to determine the static pressure variation along the axis of z and along lines adjacent to the axis of x* (*see* Fig. 1) for angles of incidence ranging from 30° to 90°. This variation of static pressure with x and with z is shown in Figs. 10(*a*) and 10(*b*).

2.2. DIRECT VISUALISATION OF THE WAKE FLOW

The small water tunnel at the N.P.L. has a working section of 10 in. × 10 in. through which the water flows vertically at a speed of 5 ft./sec. A triangular plate with 5 in. sides was held in the working section, and some particles of polystyrene suspended in the water were illuminated by a parallel beam of light issuing from a narrow slit. In this way the traces recorded were those of particles which were passing instantaneously through one selected plane, in this case always a plane containing the direction of the undisturbed stream.

*After examination of the record of the particle paths at each value of α, this horizontal line was chosen to pass through the downstream extremity of the cavity.

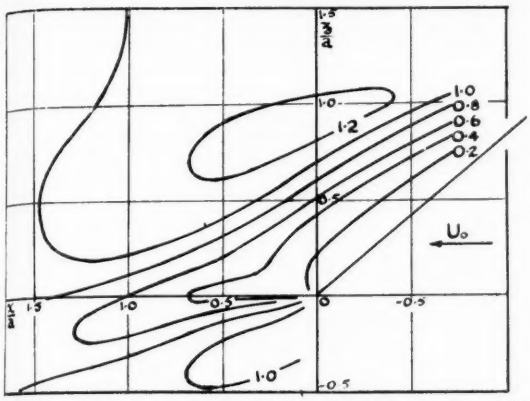


FIGURE 4. Contours of constant mean velocity measured in the plane $y/a=0$ at $\alpha=40°$.

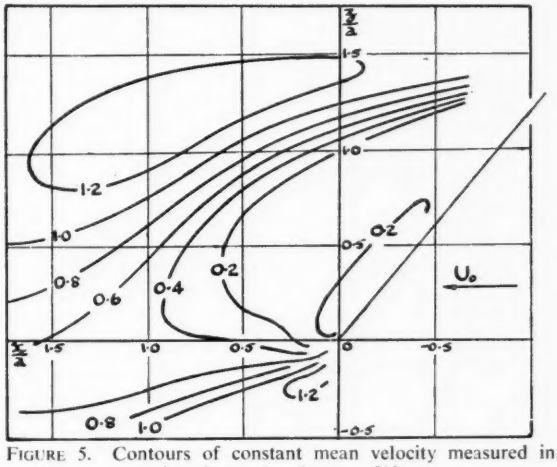
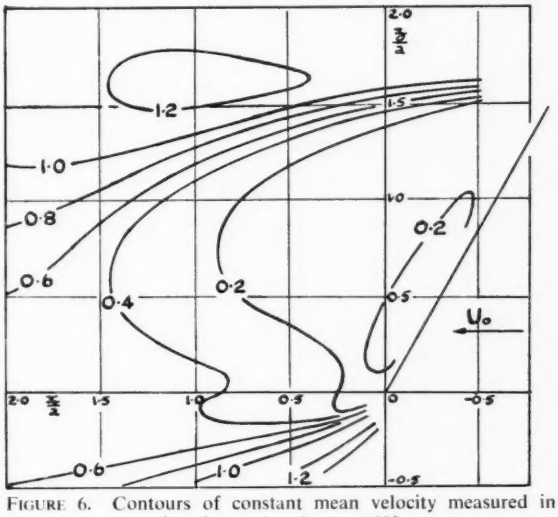


FIGURE 5. Contours of constant mean velocity measured in the plane $y/a=0$ at $\alpha=50°$.



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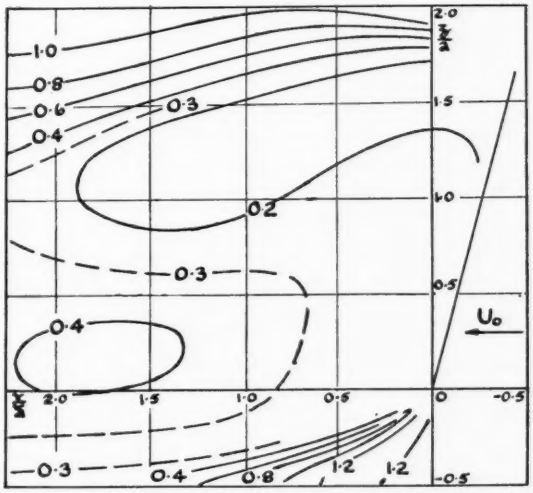

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Tests were made at angles of incidence from 30° to 75° and photographic records were made of the particle traces in a number of planes for each value of α. These records are shown in Figs. 11 to 15 (*see* p. 350).

The streamline traces shown in Figs. 16 to 21 (*see* p. 351) were obtained in a small 10 in. × 10 in. wind tunnel at Handley Page Ltd., into which the smoke filaments were introduced from a comb of tubes held upstream of the working section where the speed was about 10 ft/sec. The plate used in these tests was a small scale version of the plate which was used in the previous wind tunnel tests, having 3 in. sides.

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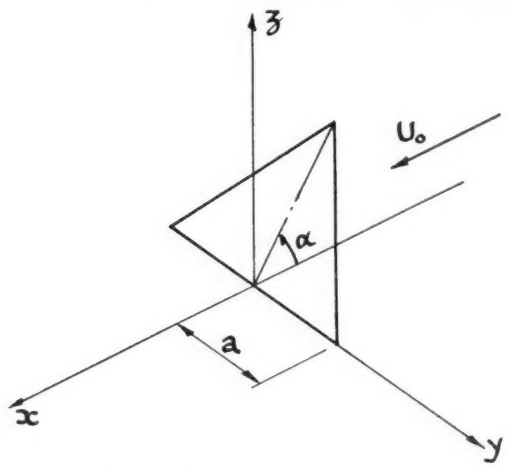
Although in both these series of tests the lower limit of inclination was 40°, the closed flow region is seen to be very small at this angle and it seems justifiable to link the initial appearance of the closed flow with the apparent stall which is indicated by the drag and lift curves as occurring at $\alpha=35°$. Some remarks on the physical meaning of this stall, which have been inferred from the results of some previous experiments on the flow past a slender delta wing at low angles of incidence (Fink and Taylor[2]), might be appropriate at this point: these earlier experiments referred to a wing with a 20° apex angle but the nature of the flow is thought to be similar for all sharp-edged delta wings with large angles of sweepback. For all angles of incidence greater than



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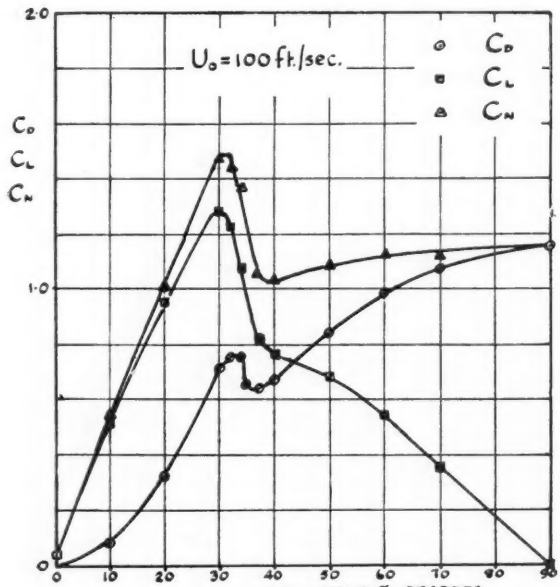

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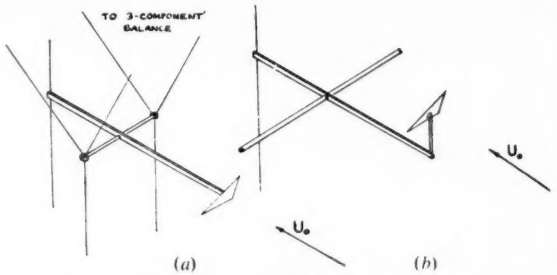

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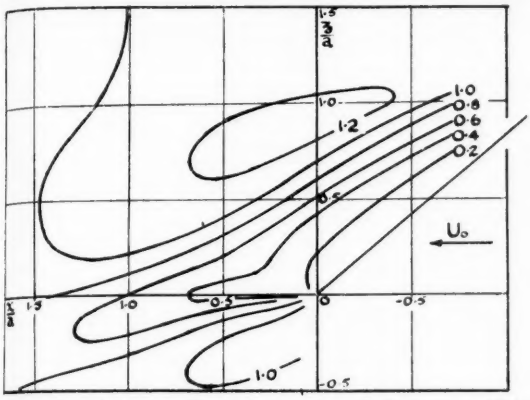
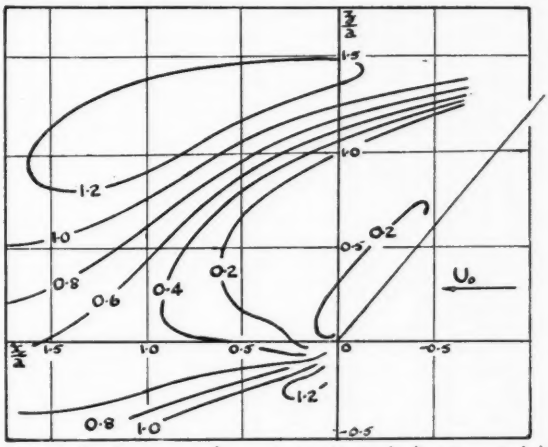


FIGURE 4. Contours of constant mean velocity measured in the plane $y/a=0$ at $\alpha=40°$.



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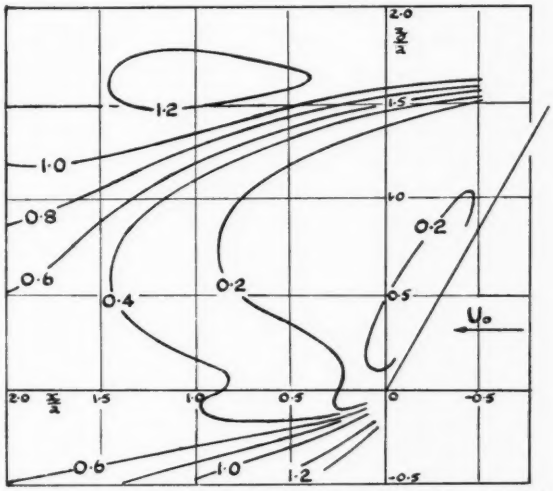

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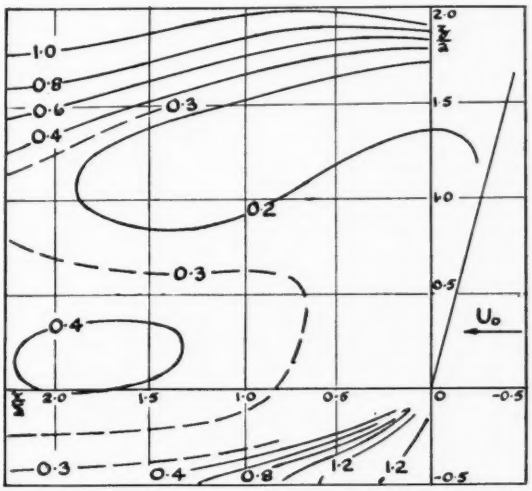

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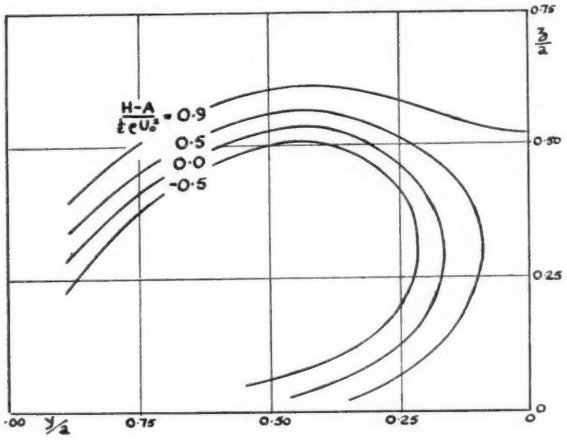

FIGURE 8(*a*) (*left*). Contours of constant total-head measured in the plane $x/a=0$ at $\alpha=30°$.

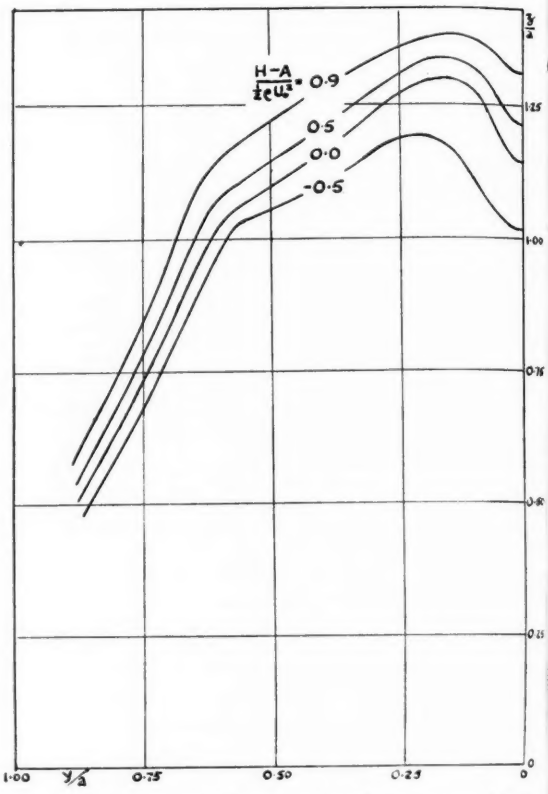

FIGURE 8(*b*). Contours of constant total-head measured in the plane $x/a=0$ at $\alpha=50°$.

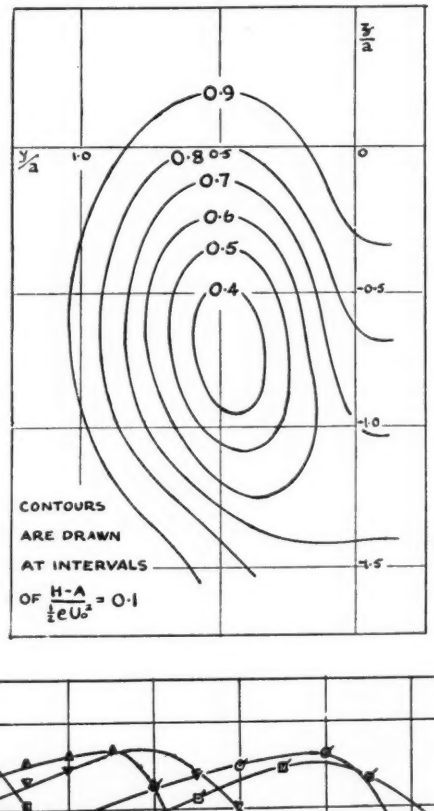

FIGURE 9 (*left*). Contours of constant total-head measured in the plane $x/a=6$ at $\alpha=40°$.

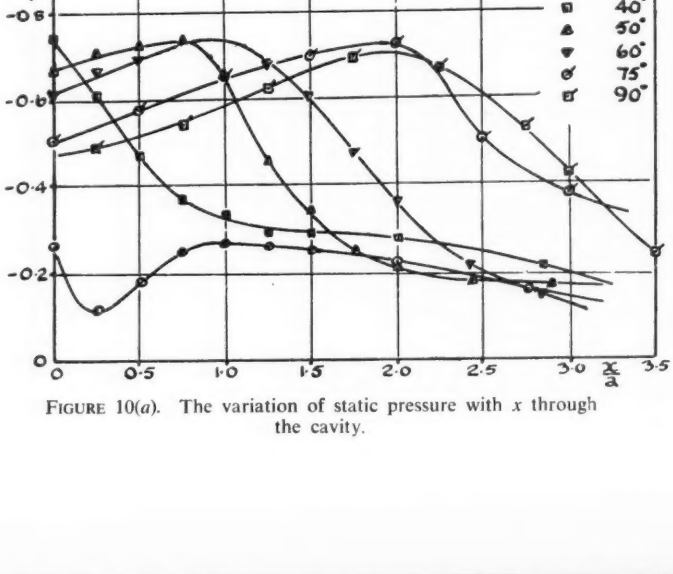

FIGURE 10(*a*). The variation of static pressure with x through the cavity.

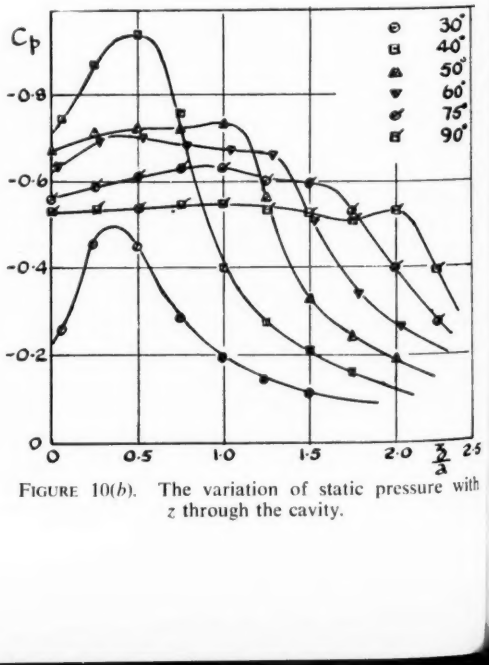

FIGURE 10(*b*). The variation of static pressure with z through the cavity.

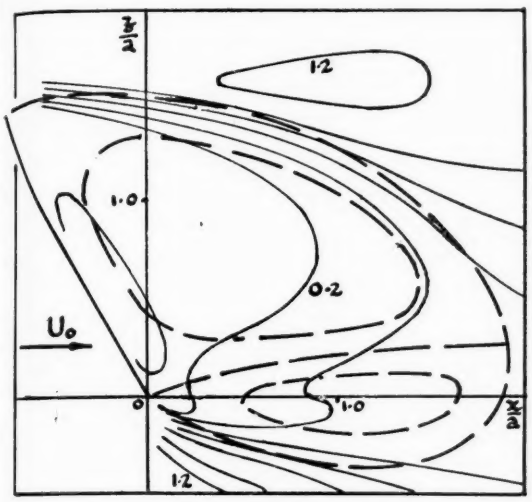

FIGURE 22. Streamline boundary estimated from Fig. 14(*a*) compared with mean velocity contours from Fig. 6. $\alpha = 60°$.

about 3°, flow separation occurs at the leading edges and this leads to the formation of two vortex sheets which quickly roll up in a conical manner, as shown in Fig. 23, to form the trailing vortices.

With this regime the streamlines flowing over the upper surface are main flow streamlines so that suction is maintained and no major regions of closed flow exist. With increasing inclination these two vortex sheets spread towards each other and roll up closer to the centre line of the plate and it seems probable, from examination of Fig. 11, that the sheets shed from each edge will ultimately meet in the centre, thus enclosing a slow moving mass of air between themselves and the vortex sheet which is shed from the trailing edge. When this happens the streamlines flowing over the upper surface of the plate are no longer main flow streamlines as they were at lower angles of incidence. The consequent reduction in the curvature of the main flow streamlines requires a higher static pressure on the upper surface of the plate and this results in a fall in the values of the lift and drag forces. Some indication of the approximate position occupied by the leading edge vortex sheets at angles of incidence above and below that of the stall may be gained from the contours of constant total head plotted in Figs. 8(*a*) and 8(*b*), since, approximately, a region of high total head gradient is a region of high vorticity.

With this new regime there must still be downwash near the centre of the plate and this seems, after a short distance downstream of the trailing edge, to split the closed flow cavity in half; this can be seen most clearly in Figs. 14(*a*) and 14(*b*): in Fig. 14(*a*) the cavity seems quite short, while in Fig. 14(*b*) the dividing streamline passes out of the region covered by the photograph. While this provides a satisfactory explanation of the existence of closed streamlines in the central plane, it gives no indication of whether we should expect the resulting two branches of the cavity to continue open or to close. The idea that they might be of indefinite length seems physically to be rather unlikely, since such a cavity cannot remain open indefinitely unless the air within is stationary and has a constant pressure equal to that of the free stream outside, and this is certainly not the case here. Cox and Clayden[4] showed that with an air-filled cavity behind a lifting plate in a water channel the two branches could continue open indefinitely, but such results were probably obtained because of the large volume of air introduced into the cavity and because of the tendency for air in such a cavity to fill any region of low pressure such as the core of a trailing vortex. We conclude, therefore, that the cavity is completely closed and probably terminates in two short horns: evidence of these horns can, in fact, be found in Figs. 12(*b*) and 12(*c*) where $\alpha = 40°$, and from these two figures it also appears that the main flow streamlines travel spirally around the horns so producing the necessary trailing vorticity. In the total head survey made downstream of the cavity (Fig. 9) two pronounced regions of low total head are seen (the contours drawn are for one half of the wake only) showing that the trailing vorticity is by this time ($x/a = 6$) nearly all concentrated in two cores whose spacing is nearly the same as that of the centres of the two horns found in Fig. 12(*c*). It would seem, therefore, that the trailing vortices grow from these two horns and if this is so then each horn probably ends in a cusp. A sketch of this type of flow is given in Fig. 24 and this may be compared with Fig. 23 which shows the probable form of the wake at a lower inclination, ($\alpha = 30°$).

Such attention to the detail of the shape of the cavity is, however, of doubtful value since the entire wake flow was found to be very unsteady, especially near the downstream end of the cavity. This unsteadiness may be attributed to the fact that the idealised steady flow already described would require something like a stagnation point at "*A*" in Fig. 24 which would be physically unrealistic, and such a paradox would not be encountered in unsteady flow. Some measurements of the spectra of the fluctuations in the wake, reported in Ref. 1, show some pronounced low frequency peaks at the higher inclinations ($\alpha > 40°$) which suggest that the unsteadiness takes the form of an oscillatory flow.

It remains now to comment on the recirculatory flow within the cavity. Figs 14(*a*), 14(*b*) and 14(*c*) show the particle paths in three different sections through the cavity for an angle of incidence of 60°, and a standing ring eddy would describe the internal flow in the most satisfactory manner. This is of course a distorted form of the eddy one would expect to find in the wake of a circular disc set normal to a stream. The distributions of static pressure plotted in Figs. 10(*a*) and 10(*b*) are typical of bubble flows in general showing a region of nearly uniform pressure, followed by a short region of pressure recovery. Comparison with the length of the cavity estimated from the results of the water tunnel tests shows that this pressure recovery is completed just downstream of the end of the cavity: thus from Fig. 22 the length of the cavity at $\alpha = 60°$ lies between $2a$ and $2{\cdot}5a$ and from Fig. 10(*a*) the static pressure rise is complete when $x = 2{\cdot}5a$.

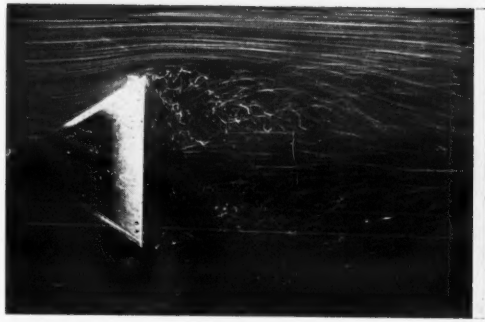

FIGURE 11. Particle paths recorded in the plane $z/a=0$ at $\alpha=30°$.

FIGURE 12(*a*). Particle paths recorded in the plane $y/a=0$ at $\alpha=40°$.

FIGURE 12(*b*). Particle paths recorded in the plane $y/a=-0{\cdot}4$ at $\alpha=40°$.

FIGURE 12(*c*). Particle paths recorded in the plane $z/a=0{\cdot}6$ at $\alpha=40°$.

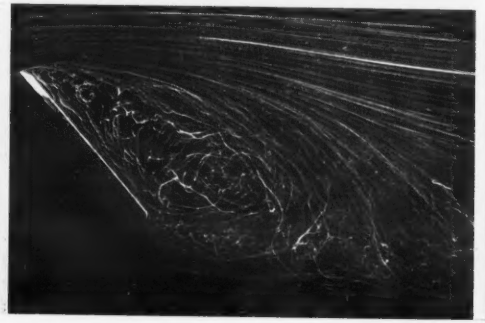

FIGURE 13. Particle paths recorded in the plane $y/a=0$ at $\alpha=50°$.

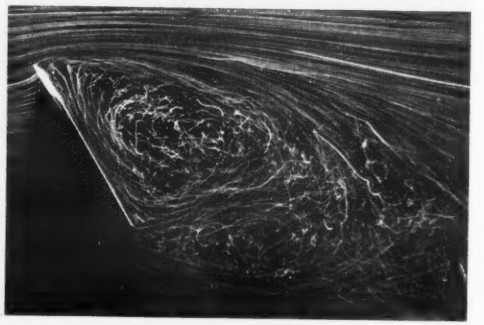

FIGURE 14(*a*). Particle paths recorded in the plane $y/a=0$ at $\alpha=60°$.

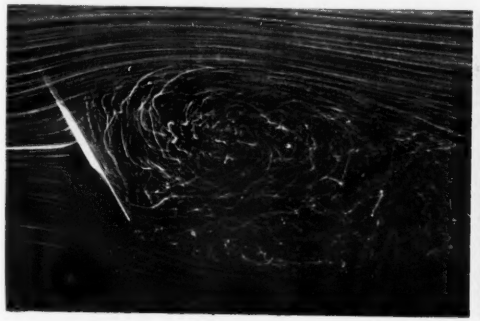

FIGURE 14(*b*). Particle paths recorded in the plane

FIGURE 14(*c*). Particle paths recorded in the plane

FIGURE 15. Particle paths recorded in the plane

FIGURE 14(*b*). Particle paths recorded in the plane

FIGURE 14(*c*). Particle paths recorded in the plane

FIGURE 15. Particle paths recorded in the plane

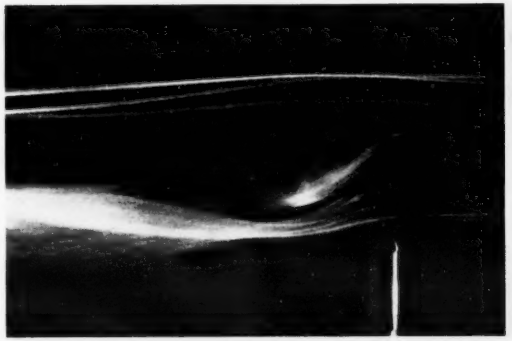

FIGURE 16. Streamline traces in the plane $y/a=0$ at $\alpha=34°$.

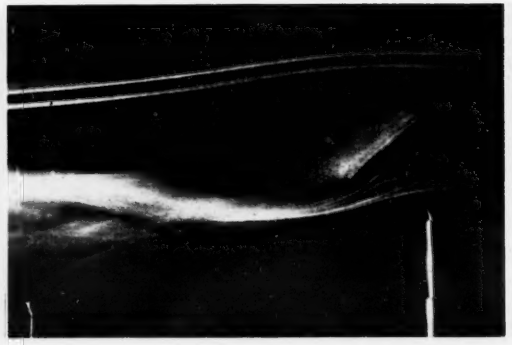

FIGURE 17. Streamline traces in the plane $y/a=0$ at $\alpha=40°$.

FIGURE 18. Streamline traces in the plane $y/a=0$ at $\alpha=50°$.

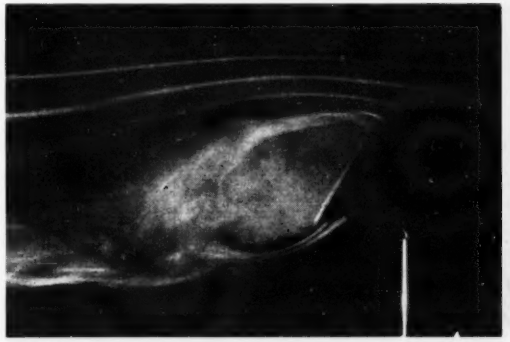

FIGURE 19. Streamline traces in the plane $y/a=0$ at $\alpha=60°$.

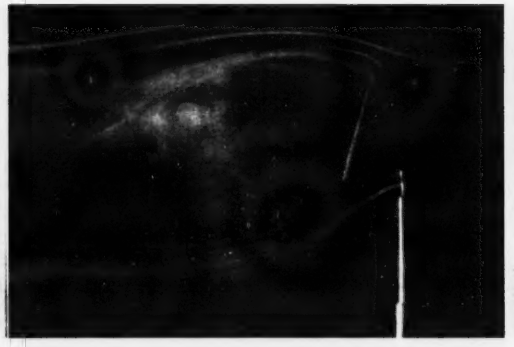

FIGURE 20. Streamline traces in the plane $y/a=0$ at $\alpha=75°$.

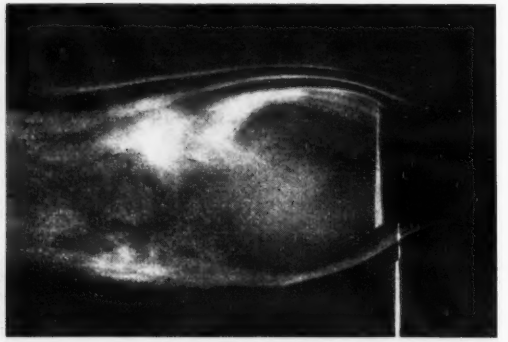

FIGURE 21. Streamline traces in the plane $y/a=0$ at $\alpha=90°$.

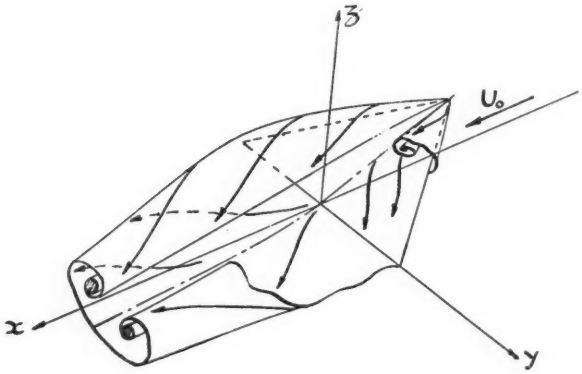

FIGURE 23. Suggested flow at $\alpha=20°$.

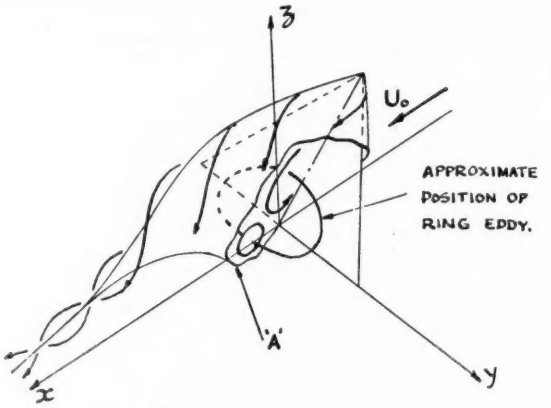

FIGURE 24. Suggested flow at $\alpha=40°$.

4. Concluding Remarks

For angles of incidence below 35°, the vortex sheets which are shed from the leading edges of the plate roll up directly to form two trailing vortices. For greater angles of incidence these vortex sheets join up above the plate to form the boundary of a cavity in the wake. It was inferred that, considering only the mean flow, this cavity was closed at its downstream end and recirculatory flow was found to be set up inside in the form of a standing ring eddy. This steady mean flow, however, implies the existence of a stagnation point which is not on a solid surface. In practice this does not occur owing to the presence of oscillations. These changes in the character of the wake flow were found to be indicated both by observations of the flow and by the changes in the values of the lift and drag forces.

Acknowledgments

The author wishes to thank Professor H. B. Squire and Mr. P. T. Fink for suggesting the investigation and for advice during its course. He is also indebted to Mr. G. H. Lee and Mr. F. R. Hounsfield of Handley Page Ltd., for placing their smoke tunnel at his disposal, and to Mr. N. C. Lambourne and Mr. P. S. Pusey of the N.P.L. for their help with the tests in their water tunnel and for the preparation of prints.

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TECHNICAL NOTES

Two-Dimensional Stress and Inertia Combinations

by

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A SIMILARITY in properties will be demonstrated between the moments and product of inertia of a lamina and the components of plane stress.

It is now a well established fact that in two-dimensional stress theory it is advantageous to use certain combinations of the stress components[1].

$$\left.\begin{aligned}\Theta &= \sigma_x + \sigma_y \\ \Phi &= \sigma_x - \sigma_y + 2i\tau_{xy}\end{aligned}\right\} \quad . \qquad (1)$$

First, it will be shown that the use of similar combinations of the moments and product of inertia leads to a useful graphical means of obtaining these quantities for awkwardly placed axes and also to some results not normally to be found in the text-books. Secondly, an application to photoelastic analysis is also made.

NOTATION

x, y, x', y'	Cartesian co-ordinates
r, θ	polar co-ordinates
σ_x, σ_y	normal stress components
τ_{xy}	shear stress components
σ_1, σ_2	principal stresses
I_x, I_y, I_{xy}	moments and product of inertia
	$i = \sqrt{(-1)}$

MOMENTS OF INERTIA

For a lamina the moments and product of inertia are given by

$$I_x = \Sigma y^2 \delta A, \quad I_y = \Sigma x^2 \delta A, \quad I_{xy} = \Sigma xy \delta A \quad . \qquad (2)$$

On rotation of the axes through an angle α to $x'Oy'$

$$\left.\begin{aligned}x' &= x\cos\alpha + y\sin\alpha \\ y' &= -x\sin\alpha + y\cos\alpha\end{aligned}\right\} \quad . \quad . \qquad (3)$$

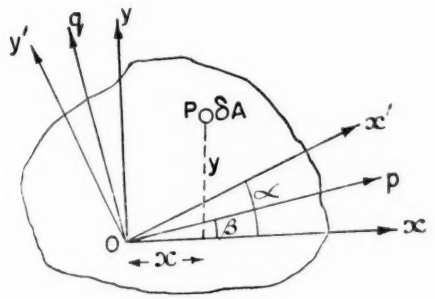

FIGURE 1.

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for a point P, and the new moments and product with respect to these axes become

$$\left.\begin{aligned}I_{x'} &= I_x\cos^2\alpha - I_{xy}\sin 2\alpha + I_y\sin^2\alpha \\ I_{y'} &= I_x\sin^2\alpha + I_{xy}\sin 2\alpha + I_y\cos^2\alpha \\ I_{x'y'} &= \tfrac{1}{2}(I_x - I_y)\sin 2\alpha + I_{xy}\cos 2\alpha.\end{aligned}\right\} \quad . \qquad (4)$$

The last of equations (4) shows that the principal directions (Op, Oq in Fig. 1) which are given by $I_{x'y'} = 0$ correspond to

$$\alpha = \tfrac{1}{2}\tan^{-1}\frac{2I_{xy}}{I_y - I_x} \ (=\beta \text{ say}) \quad . \quad . \qquad (5)$$

INERTIA COMBINATIONS

Writing
$$\left.\begin{aligned}\Lambda &= I_x + I_y \\ \text{and} \quad \Gamma &= I_y - I_x + 2iI_{xy}\end{aligned}\right\} \quad . \quad . \quad . \qquad (6)$$

and, for the new axes

$$\left.\begin{aligned}\Lambda' &= I_{x'} + I_{y'} \\ \Gamma' &= I_{y'} - I_{x'} + 2iI_{x'y'}\end{aligned}\right\} \quad . \quad . \quad . \qquad (7)$$

it can be shown from (4) that

$$\left.\begin{aligned}\Lambda' &= \Lambda \\ \text{and} \quad \Gamma' &= \Gamma e^{-2i\alpha}\end{aligned}\right\} \quad . \quad . \quad . \quad . \qquad (8)$$

It should be noted that the argument of the complex quantity Γ is 2β so that it may be written

$$\Gamma = |\Gamma| e^{2i\beta} \quad . \quad . \quad . \quad . \qquad (9)$$

where
$$|\Gamma| = \{(I_y - I_x)^2 + 4I_{xy}^2\}^{\frac{1}{2}} \quad . \quad . \qquad (10)$$

Equations (8) show that Λ and $|\Gamma|$ are quantities which are invariant to the rotation of axes.

GRAPHICAL REPRESENTATION

It follows from equation (6) that

$$\left.\begin{aligned}I_y + iI_{xy} &= \tfrac{1}{2}(\Lambda + \Gamma) \\ \text{and} \quad I_x - iI_{xy} &= \tfrac{1}{2}(\Lambda - \Gamma)\end{aligned}\right\} \quad . \quad . \qquad (11)$$

Similarly from (7).

$$\left.\begin{aligned}I_{y'} + iI_{x'y'} &= \tfrac{1}{2}(\Lambda' + \Gamma') \\ I_{x'} - iI_{x'y'} &= \tfrac{1}{2}(\Lambda' - \Gamma')\end{aligned}\right\} \quad . \quad . \qquad (12)$$

It is possible now to draw what amounts to an Argand diagram on which to represent the above quantities. (It may also be recognised as analogous to Mohr's stress circle diagram).

Assuming that the quantities I_x, I_y and I_{xy} are known, since they may be evaluated for simply placed axes (for which I_{xy} may well be zero), the diagram allows $I_{x'}$, $I_{y'}$ and $I_{x'y'}$ to be measured.

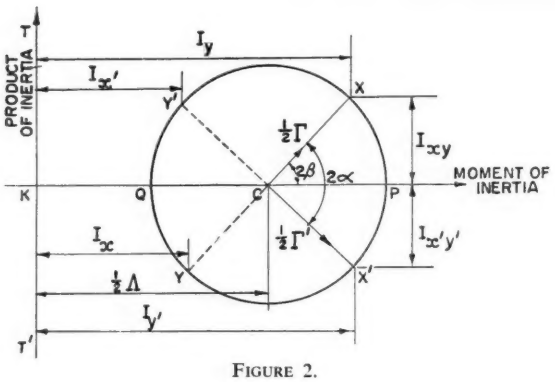

FIGURE 2.

In the diagram two perpendicular axes KC and TKT' are taken, along which the moment and product of inertia respectively are plotted.

Vectorially, $\overrightarrow{KC}=\frac{1}{2}\Lambda$, $\overrightarrow{CX}=\frac{1}{2}\Gamma$ and $\overrightarrow{CX'}=\frac{1}{2}\Gamma'$.

The construction is therefore to draw a circle of radius $\frac{1}{2}|\Gamma|$ as given by (10) and centre at $C(\frac{1}{2}\Lambda, 0)$. Axes Op, x'; y, q, y', x taken anticlockwise on Fig. 1 are then represented by the points P, X', Y, Q, Y', X taken clockwise at twice the angular rotation on Fig. 2. Points X and Y may be plotted from the known information and then for a given angle α the perpendicular distances of the points X' and Y' from the axes TKT' and KC give the appropriate moment and product of inertia for the axes Ox' and Oy'.

The diagram shows that

(*i*) the principal moments I_1 and I_2 are given by KP and KQ as

$$I_1, I_2=\tfrac{1}{2}(\Lambda\pm|\Gamma|)$$
$$=\tfrac{1}{2}(I_x+I_y)\pm\{\tfrac{1}{4}(I_y-I_x)^2+I_{xy}^2\}^{\frac{1}{2}} \quad . \quad (13)$$

(*ii*) the product of inertia changes sign as an axis passes through Op or Oq.

PLANE STRESS ANALYSIS

In this case certain other quantities which may be derived from the stress combinations assume physical significance.

Thus, the principal stresses σ_1 and σ_2 are given by

$$\sigma_1, \sigma_2=\tfrac{1}{2}(\Theta+|\Phi|) \quad . \quad . \quad (14)$$

so that the maximum shearing stress becomes

$$\tau_{max}=\tfrac{1}{2}(\sigma_1-\sigma_2)=\tfrac{1}{2}|\Phi|. \quad . \quad . \quad (15)$$

It is of particular interest to see how some of the fundamental ideas of photoelastic stress analysis follow from this approach.

TWO-DIMENSIONAL PHOTOELASTIC ANALYSIS

Many of the important concepts, for which the reader is referred to standard text-books[2], are easily expressed in terms of the stress combinations.

Two of the basic sets of curves which are used are the *isoclinics* and the *isochromatics*.

An *isoclinic* is the locus of points at which the principal axes of stress are in a given fixed direction and may be written

$$\arg\Phi=\text{const.} \quad . \quad . \quad . \quad (16)$$

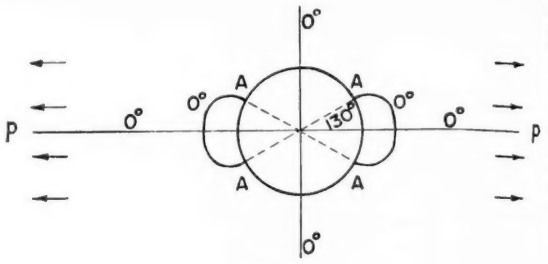

FIGURE 3.

An *isochromatic* is a curve along which the maximum shearing stress has a constant value, so that

$$|\Phi|=\text{const.} \quad . \quad . \quad . \quad (17)$$

An *isotropic point* at which $\sigma_1=\sigma_2$ is, therefore, from (14), a point where

$$|\Phi|=0.$$

In this case the circle diagram of Fig. 2 would reduce to a point at C, so that all directions through an isotropic point have zero shear associated with them. Also, since the argument of Φ could then be arbitrary it is clear from (16) that isoclinics of any angle may pass through an isotropic point.

APPLICATION

It is of interest to see how (16) leads to the actual equation of an isoclinic.

Consider the case of a large plate under tension p in the x-direction, and containing a circular hole of radius a.

Using the method of Ref. 1 the solution may be expressed in terms of two complex potentials $\Omega(z)$ and $\omega(z)$ where $z=x+iy$, the stress combinations being given by

$$\left.\begin{aligned}2\Theta&=\Omega'(z)+\overline{\Omega}'(\bar{z})\\ 2\Phi&=-z\overline{\Omega}''(\bar{z})-\overline{\omega}''(\bar{z})\end{aligned}\right\} \quad . \quad (19)$$

For this problem the values of the complex potentials are

$$\Omega(z)=p\left(z+\frac{2a^2}{z}\right). \quad . \quad . \quad (20)$$

$$\omega(z)=-p\left(z^2+\frac{a^4}{z^2}+2a^2\log z\right). \quad . \quad (21)$$

so that $$\Phi=p\left[1-\frac{a^2}{r^2}e^{2i\theta}+\left(\frac{3a^4}{r^4}-\frac{2a^2}{r^2}\right)e^{4i\theta}\right] . \quad (22)$$

where $$z=re^{i\theta}.$$

The 0° isoclinic is then given as

$$-\frac{a^2}{r^2}\sin 2\theta+\left(\frac{3a^4}{r^4}-\frac{2a^2}{r^2}\right)\sin 4\theta=0$$

$$\text{giving } \sin 2\theta=0 \text{ and } r^2=\frac{6a^2\cos 2\theta}{1+4\cos 2\theta} \quad . \quad (23)$$

Figure 3 shows the position of this isoclinic, and isotropic points at A.

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A Test Plant for Helicopter Engines

by

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THIS NOTE describes the design and construction of a "Tilting Test Bed" for helicopter engines for Alvis Ltd., for which some onerous requirements were laid down (Fig. 1). The most important of these were that:—

(*i*) Readings of engine torque and b.h.p. must be given by a dynamometer, so as to provide accurate data.

(*ii*) The engine, and therefore the complete test plant, must be capable of being tilted, while running, through 120°—from the horizontal to the vertical and 30° beyond.

(*iii*) During the tilting process the engine throttle setting must remain unaffected and the readings of torque, b.h.p., fuel consumption, and so on, continue with unaltered accuracy.

(*iv*) A powerful fan must be incorporated, for cooling certain types of engine not provided with self-contained fan, and the air-blast must continue unchanged during tilting.

The conventional layout of wind tunnel test plants for aircraft engines consists of an engine cradle, transmission shafting dynamometer, geared starting motor and cooling fan with motor and wind tunnel, and is thus of considerable length; for the particular engines made by Alvis Limited, this would be of the order of 40 to 50 ft. To arrange such a plant on a deep girder structure, pivoted in the centre, would have given an excessively cumbrous layout, requiring a building height of over 90 ft., and introducing complications in piping, cabling, and so on. Moreover, it would have been impossible to keep the engine in view from the control room throughout its range of movement.

Consideration of these problems led to a neat solution. In principle, this consisted of removing some of the essential items from the tilting portion of the test plant, arranging them on the axis of tilt on fixed foundations, and ensuring that they remained effective at all tilt angles. These items were the large cooling fan with its variable-speed drive, and the geared starting-motor; by this means the overall length of the tilting portion, with engine in place, was reduced to some 20 ft., its weight was brought down to manageable proportions, and the height of the building was rendered quite practicable, in fact little greater than that of the other test-houses on the site.

Physically, these results were obtained by providing the tilting portions with circular roller tracks, of about 8 ft. diameter, instead of with central pivots. Two such circular tracks were provided, one at each end of a fairly massive

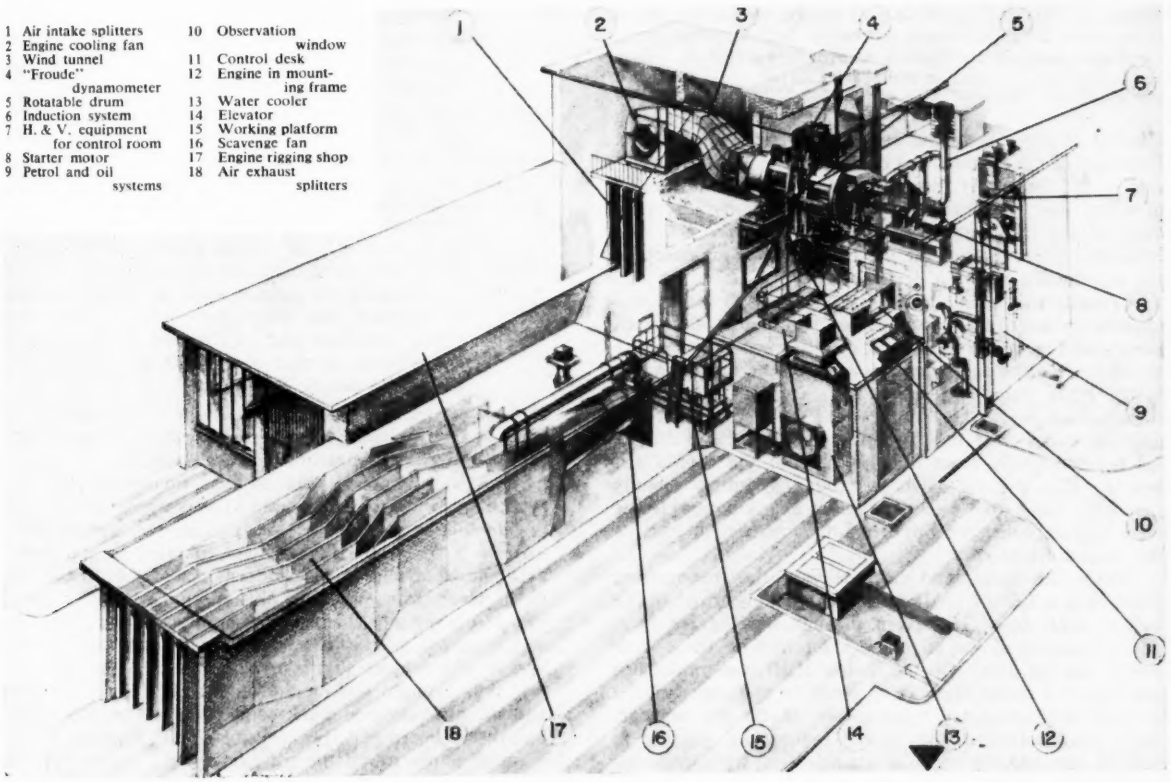

FIGURE 1. Universal test bed for helicopter engines.

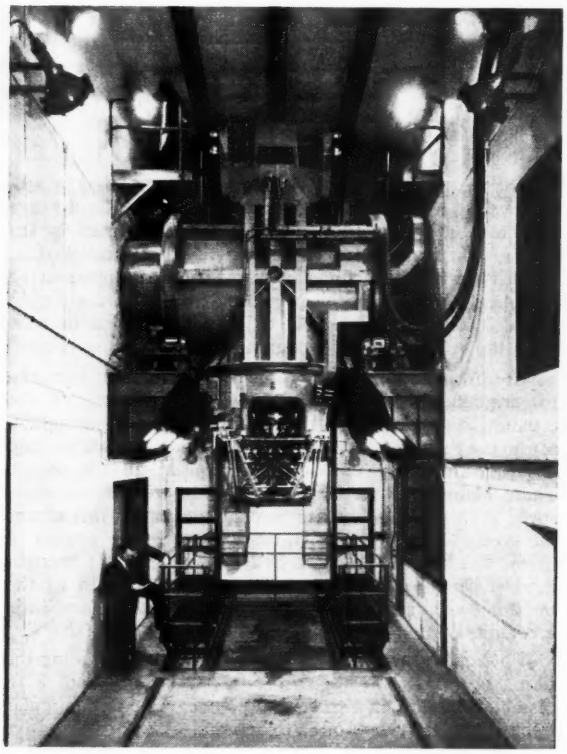

FIGURE 2. This photograph shows a general view of the engine room of the helicopter engine test bed at Baginton. This equipment was designed by Heenan & Froude Limited in collaboration with Alvis Ltd.

cylinder of about the same diameter and some 10 ft. long. Each end of the cylinder was closed; at one end the closure was in the form of an annular plate, the central portion of which was a clearance fit round the circular discharge duct of the cooling fan which was co-axial with the cylinder. Thus rotation of the cylinder had no effect on the fan ducting and fan performance.

Crossing this cylinder at right angles at its centre was another cylinder, the two together forming a 90° cross-piece (*see* Fig. 2). This second cylinder was the structure which carried the engine at one end and the dynamometer at the other, coupled together by a Cardan shaft and a transmission shaft, the latter carried in its own bearings. Cascade vanes were fitted internally to direct the cooling air flow smoothly from the fan duct to the engine air-nozzle. The dynamometer (a Froude hydraulic directly reversible type) and the engine on its mounting frame were each cantilevered out from their respective ends of the second cylinder.

Inside the latter, and co-axial with the transmission shaft, was a hollow shaft in independent bearings. The hollow shaft could be driven through bevel gears by a geared starting motor, mounted externally on the centre-line of the tilt axis. On the hollow shaft was mounted a conventional starter claw which could be engaged with the engine-to-dynamometer transmission shaft; the arrangement thus permitted the starter motor and gearing to remain permanently on fixed foundations, while allowing tilting to be carried out at will.

While the foregoing provisions successfully overcame

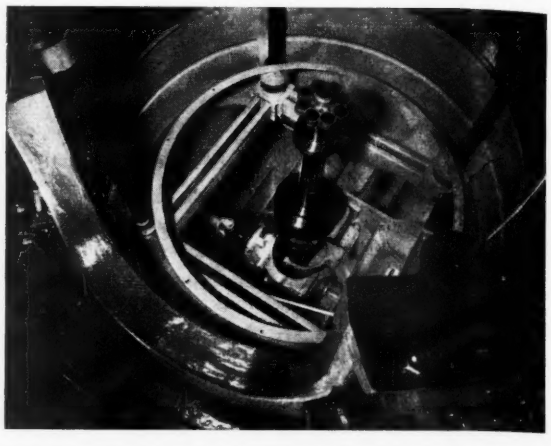

FIGURE 3. The interior view of the rotatable drum of the helicopter engine test plant showing the Cardan shaft for conection to the engine.

the main problems, there remained a number of other difficulties. The necessity of keeping the throttle setting unaltered during tilting was met by a method which can best be described by tabulating the sequence of operations as follows:—

(*i*) The throttle lever on the control panel is locked by a magnetic friction clutch to a lever shaft, free to rotate in its own bearings, mounted in the tilting structure on the centre-line of the tilt axis. The same action, through a second clutch, locks this shaft to a lever (the boss of which surrounds the shaft) coupled to the throttle mechanism on the engine.

(*ii*) The lever on the control panel is then adjusted to give the throttle setting desired.

(*iii*) When it is wished to tilt the engine, the first clutch is disconnected and, at the same time, the lever shaft is held from moving by energising a magnetic brake which clamps it to the tilting structure itself; the engine throttle setting is thus preserved throughout the tilting process.

(*iv*) On reaching the desired angle of tilt, the process is reversed; the lever shaft is freed from the tilting structure and re-clutched to the control room lever, so that the engine throttle is again under the tester's control.

Various means, including hydraulic force-transmitting gear, were considered for transmitting the torque-reaction forces from the dynamometer lever arm to the control panel. A mechanical solution was finally adopted, the system centering round the use of levers which transformed the angular oscillation of the dynamometer casing under load to a fore-and-aft movement, parallel to the lateral axis joining dynamometer and engine. By arranging the shaft which was subject to this motion a short distance away from the lateral axis, a bell-crank could be interposed which served a double purpose, firstly the final motion was at right-angles to the dynamometer-engine axis and was thus brought out on the other axis, *i.e.* the tilt axis, and secondly, the bell-crank connection was by means of a ball-thrust bearing. The effect was that rotation of the main structure round the tilt axis merely caused rotation of one member of the thrust bearing and did not affect the forces the latter was transmitting.

A minor problem was that means had to be provided for checking, by dead-weights, the accuracy with which the dynamometer load was transmitted to the control room for calculation of torque and b.h.p. The checking process had to be applicable at any angle of tilt, and to either sense of the forces corresponding with right-hand or left-hand rotation of the dynamometer. This led to the use of flexible steel tapes, passing round pulleys, for connecting the test weights to the dynamometer; this ensured that, regardless of the angle of tilt, the true gravitational force due to the weights was always transmitted to the dynamometer, for comparison with the reading indicated on the weigher dial in the control room.

The process of fitting the engine into position for test was solved by using a cradle on which the engine, in its test mounting frame, was run on to a hydraulic lift directly underneath the tilting structure, the latter being set in the vertical position. The lift was then raised until four wire cables, depending from the structure, could be hooked into lifting eyes on the mounting frame. The cables were then winched up by hand, all together, until the engine was in its final position and the locating bolts could be fitted; the lift was then lowered and the empty cradle removed.

While those given were the most obvious points which had to be catered for, there were naturally a great number of general and detail features which needed consideration. The design of the engine cardan shaft alone (Fig. 3) was a difficult problem, necessitating the combination of quick connection and disconnection with security while running, and other points of layout and detail could be mentioned.

There was also the problem of connecting the fixed portions of the air supply system (boost fan, air heater/cooler, depression valve, and so on) to the engine carburettor; once more the principle was adopted of arranging the external air ducting co-axial with and surrounding the shafting connecting the engine starting motor to the bevel gears inside the rotating cylinder, this shafting being itself on the axis of tilt. Ducting inside the cylinder formed part of the rotating equipment and could, therefore, be readily coupled to the engine carburettor.

Throughout the design of this equipment there was naturally very close co-operation between the two firms involved and this was a major factor in designing "from a clean sheet of paper" a plant which is thought to be unique.

ACKNOWLEDGMENT

The work described in this note was done by the author's colleagues in Heenan and Froude Ltd.

Buckling of Simply-Supported Rhombic Plates Under Externally Applied Shear

by

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THE buckling of skewed plates with clamped edges and under externally applied shear, and skewed plates with simply-supported edges but with both externally applied axial and shear loading have been considered previously[1-3]. It is the purpose of the present note to consider the buckling of simply-supported rhombic plates under externally applied shear as shown in Fig. 1.

The buckling load is determined by the method of collocation[4-6]. The most general deflected shape of the plate at buckling may be written:

$$w=\sum_{p}\sum_{q}\sum_{r}\sum_{k}\sum_{m}\sum_{n}\alpha_{pqrkmn}\cos^{p}\left(\frac{k\pi y}{2b}\right)\cos^{q}\left(\frac{\frac{m\pi x}{2a}}{1+\frac{y}{b}}\right)\cos^{r}\left(\frac{\frac{n\pi x}{2a}}{1-\frac{y}{b}}\right) \quad . \quad . \quad (1)$$

However, in the present calculations, only two terms are taken such that:

$$w=\left[4\alpha_1\cos^{3}\left(\frac{\pi y}{2b}\right)+8\alpha_2\cos^{4}\left(\frac{\pi y}{2b}\right)\right]\cos\left(\frac{\frac{\pi x}{2a}}{1+\frac{y}{b}}\right)\cos\left(\frac{\frac{\pi x}{2a}}{1-\frac{y}{b}}\right) \quad . \quad (1a)$$

$$=F\cos\theta_1\cos\theta_2$$

and (b/a) is limited to lie in the range:

$$0{\cdot}5\leqslant\left(\frac{b}{a}\right)\leqslant 1{\cdot}5 \quad . \quad . \quad (1b)$$

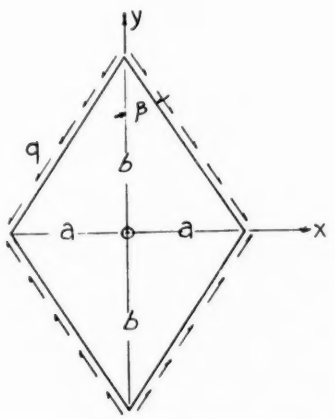

FIGURE 1. Rhombic plate and loading.

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The differential equation defining buckling of the plate may be written in rectangular co-ordinates as:

$$D\nabla^4 w + N_x \frac{\partial^2 w}{\partial x^2} + N_y \frac{\partial^2 w}{\partial y^2} = 0 \quad . \quad (2)$$

where

$$N_x = q\left(\frac{a}{b}\right), \quad N_y = -q\left(\frac{b}{a}\right) \quad . \quad . \quad (2a)$$

From Ref. 6, the following partial derivatives of w at $x=0$, *i.e.* along the y-axis, may be written:

$$\frac{\partial^2 w}{\partial x^2} = -F\left[\frac{1}{\left(1+\frac{y}{b}\right)^2} + \frac{1}{\left(1-\frac{y}{b}\right)^2}\right]\left(\frac{\pi}{2a}\right)^2;$$

$$\frac{\partial^2 w}{\partial y^2} = F''; \quad \frac{\partial^4 w}{\partial y^4} = F''''$$

$$\frac{\partial^4 w}{\partial x^4} = F\left[\frac{1}{\left(1+\frac{y}{b}\right)^4} + 6\,\frac{1}{\left(1+\frac{y}{b}\right)^2}\frac{1}{\left(1-\frac{y}{b}\right)^2} + \frac{1}{\left(1-\frac{y}{b}\right)^4}\right]\left(\frac{\pi}{2a}\right)^4 \quad . \quad . \quad (3)$$

$$\frac{\partial^4 w}{\partial x^2 \partial y^2} = -\left\{F''\left[\frac{1}{\left(1+\frac{y}{b}\right)^2} + \frac{1}{\left(1-\frac{y}{b}\right)^2}\right]\left(\frac{\pi}{2a}\right)^2 + 4F'\left[-\frac{1}{\left(1+\frac{y}{b}\right)^3} + \frac{1}{\left(1-\frac{y}{b}\right)^3}\right]\left(\frac{\pi}{2a}\right)^2\left(\frac{1}{b}\right) + 6F\left[\frac{1}{\left(1+\frac{y}{b}\right)^4} + \frac{1}{\left(1-\frac{y}{b}\right)^4}\right]\left(\frac{\pi}{2ab}\right)^2\right|$$

Substitution into equation (2) and multiplication by $\left(\frac{b}{\pi}\right)^4$ yields at $y=0$:

$$F''''\left(\frac{b}{\pi}\right)^4 - F''\left(\frac{b}{\pi}\right)^2\left(\frac{b}{a}\right)^2 + F\left[\frac{1}{2}\left(\frac{b}{a}\right)^4 - \frac{6}{\pi^2}\left(\frac{b}{a}\right)^2\right] + \lambda\left[F''\left(\frac{b}{\pi}\right)^2\left(\frac{b}{a}\right) + \frac{1}{2}F\left(\frac{b}{a}\right)\right] = 0 \quad . \quad . \quad (4)$$

where at $y=0$,

$$F = 4\alpha_1 + 8\alpha_2; \quad F''\left(\frac{b}{\pi}\right)^2 = -(3\alpha_1 + 8\alpha_2);$$

$$F''''\left(\frac{b}{\pi}\right)^4 = (5{\cdot}25\,\alpha_1 + 20\,\alpha_2) \quad . \quad . \quad (4a)$$

and λ is defined by the relation:

$$q_{cr} = \frac{\lambda \pi^2 D}{b^2} \quad . \quad . \quad . \quad (4c)$$

There remains to consider the boundary conditions. From Ref. 6, the moment along the edge of the present plate may be written:

$$\frac{M}{D} = \frac{\partial^2 w}{\partial y^2}\sin^2\beta + \frac{\partial^2 w}{\partial x \partial y}\sin^2\beta + \frac{\partial^2 w}{\partial x^2}\cos^2\beta \quad . \quad (5)$$

Substitution of the partial derivatives evaluated along the edge and simplification yields for vanishing moment:

$$F\left\{\frac{-1}{\pi\left(1-\frac{y}{b}\right)^2} + \left[\frac{-1}{2\left(1+\frac{y}{b}\right)^2} + \frac{1}{2\left(1-\frac{y^2}{b^2}\right)}\cot^2\beta\right]\tan\theta_1\right\} - F'\left(\frac{b}{\pi}\right)\left(\frac{1}{1-\frac{y}{b}}\right)(1+\cot\beta\cos^2\beta) = 0 \quad . \quad (6)$$

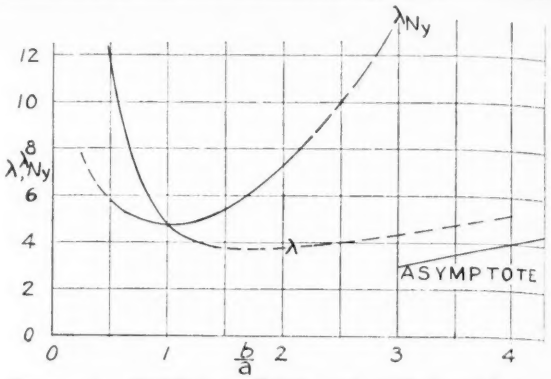

FIGURE 2. Buckling coefficient and vertical axial stress coefficient against $\frac{b}{a}$

In the present problem, the moment is made to vanish at $y=\frac{1}{4}b$ where

$$F = (3{\cdot}154\,\alpha_1 + 5{\cdot}828\,\alpha_2),$$

$$-F'\left(\frac{b}{\pi}\right) = (1{\cdot}960\,\alpha_1 + 4{\cdot}828\,\alpha_2) \text{ and } \theta_1 = 54^\circ \quad . \quad 6(a)$$

Collocation of the differential equation at the origin of co-ordinates, *i.e.* $x=y=0$ (equation 4) and satisfaction of the boundary condition at the point, $y=\frac{1}{4}b$, $x=(3/4)a$ (equation 6), yields two simultaneous equations in the unknowns α_1, α_2, and λ. Solution yields the value of the buckling coefficient, λ. For example, for $a=b$, the equations are:

$$3{\cdot}064\,\alpha_1 + 8{\cdot}073\,\alpha_2 = 0, \quad (7{\cdot}826 - \lambda)\,\alpha_1 + (27{\cdot}15 - 4\lambda)\,\alpha_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

so that:

$$\alpha_2 = -0{\cdot}379\,\alpha_1, \text{ and } \lambda = \frac{7{\cdot}826 - 0{\cdot}379\,(27{\cdot}15)}{1 - 0{\cdot}379\,(4)} = 4{\cdot}7 \quad (7a)$$

Similar calculations have been carried out for $\frac{b}{a} = 0{\cdot}5$ and $\sqrt{2}$. The resulting values of λ are shown plotted in Fig. 2. The dashed portion of the curve beyond $\frac{b}{a} = 1{\cdot}5$, represents extrapolation for larger values of $\frac{b}{a}$ where it can be shown λ approaches the value $\frac{b}{a}$. Also shown are the corresponding values of λ_{N_y}, where

$$N_y = -\lambda_{N_y}\frac{\pi^2 D}{b^2} \quad . \quad . \quad . \quad (8)$$

It is seen that although λ decreases in value for $1 < \frac{b}{a} < 2$, the intensity of the vertical axial stress actually increases.

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Comments on Some Recent Calculations Relating to the Laminar Boundary Layer with Discontinuously Distributed Suction

by

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IN REFERENCES (1), (2), Dr. Lachmann develops a method for calculating the growth of the laminar boundary layer over an aerofoil surface with spanwise suction slots placed at intervals along the chord. For this form of control, the laminar flow develops normally from the downstream edge of a slot until it attains the critical Reynolds number (expressed in terms of either the displacement or momentum thickness) at which transition is imminent. The layer then encounters another slot which so thins and stabilises the part not removed by suction, that it is able to continue downstream in the laminar state.

A new feature of the above investigation is the establishment of a second critical Reynolds number which provides an initial condition on the downstream side of a slot. Essentially it defines the minimum value of the displacement or momentum thickness for which, in relation to the local surface roughness, there is no danger of transition due to this form of disturbance. Thus, given these initial and end conditions, referred to as the " lower " and " upper " limits respectively, the slot spacing and the development of the laminar boundary layer may be calculated by any of the established methods. Apart, therefore, from the region near the leading edge where, due to the natural stabilising effect of the favourable pressure gradient, suction is unnecessary, a characteristic thickness of the layer does not increase continuously with distance in the stream direction, but alternates between the limits referred to above, so giving a saw-tooth profile along the surface of the aerofoil.

It is also of interest to determine the amount of the boundary layer removed at each slot. Here Dr. Lachmann uses a rather artificial assumption relating the velocity profile immediately downstream of a slot to that just in front of it. His relevant results, which check satisfactorily with experiment, may be obtained, however, in the following manner.

Consider, first, the flow in the immediate vicinity of a slot (Fig. 1). At some distance y_s on the upstream side there will be a streamline AB for which B is a stagnation point on, or close to, the rear lip of the slot. Thus, flow between the surface and AB enters the slot, while that exterior to AB passes downstream as the modified boundary layer. We now take two sections 1, 2 which are directly upstream and downstream of the slot respectively and calculate the momentum change within the interval, namely, the change due to (*a*) withdrawal of fluid, (*b*) dissipation of flow along the surface.

Let x be the surface co-ordinate in the streamwise direction, y the outward normal to the surface, s the slot width, u the velocity in the boundary layer at a point (x, y), U the corresponding Bernoulli value and ρ the fluid density. We will begin by dealing with (*b*) above, which we shall regard as the ordinary boundary layer flow over a slot without suction. Write the momentum equation in the form

$$\frac{dM}{dx} + \rho U \frac{dU}{dx}\delta^* = \tau_0, \qquad . \qquad (1)$$

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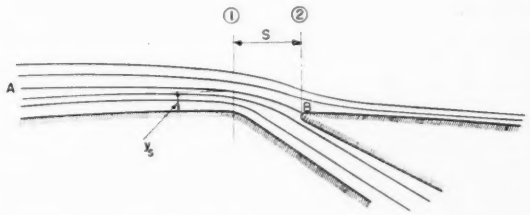

FIGURE 1. Flow in the neighbourhood of a suction slot.

where τ_0 is the surface shear stress, and the momentum loss M and displacement thickness δ^* are defined as

$$M = \rho \int_0^\infty u\,(U-u)\,dy,$$

$$\delta^* = \int_0^\infty \left(\left(1 - \frac{u}{U}\right)\right) dy.$$

Suppose, now, that the slot width s is sufficiently small that over the interval $x_1 < x < x_2$, where $x_2 - x_1 = s$, the displacement thickness δ^* and velocity U may be expressed linearly by the relations

$$\delta^* = a_0 + a_1 x. \qquad . \qquad . \qquad . \qquad (2)$$

$$U = b_0 - b_1 x. \qquad . \qquad . \qquad . \qquad (3)$$

Further, since the flow across the slot is not in contact with a solid boundary, $\tau_0 = 0$. Then the momentum equation reduces to

$$\frac{dM}{dx} - \rho b_1 (a_0 + a_1 x)(b_0 - b_1 x) = 0,$$

or,

$$\frac{dM}{dx} = \rho b_1 [a_0 b_0 + (a_1 b_0 - a_0 b_1) x],$$

to the order of accuracy of (2), (3). Hence, integrating across the slot,

$$M_2 - M_1 = \rho b_1 \int_0^s [a_0 b_0 + (a_1 b_0 - a_0 b_1)\, x]\, dx$$

$$= \rho a_0 b_0 b_1 s \left[1 + \frac{1}{2}\left(\frac{a_1}{a_0} - \frac{b_1}{b_0}\right) s\right],$$

where the suffixes 1, 2 to M denote, respectively, values at sections 1, 2.

But for normal values of a_0, a_1, b_0, b_1, s,

$$\frac{1}{2}\left(\frac{a_1}{a_0} - \frac{b_1}{b_0}\right) s << 1\dagger.$$

†An exception occurs in the case of the Griffith aerofoil with a suction slot at the point where the surface velocity is theoretically discontinuous, and where, in practice, the gradient is very large.

Therefore, we may write

$$M_2 - M_1 = \rho a_0 b_0 b_1 s = \rho \delta_1^* U_1 (U_1 - U_2), \quad . \quad . \quad (4)$$

since, clearly from (2), (3),

$$a_0 = \delta_1^*, \; b_0 = U_1, \; b_1 = -\frac{dU}{dx} = \frac{U_1 - U_2}{s},$$

the suffixes to δ^* and U also referring to conditions at sections 1, 2. Thus, the momentum change (Equation 4) may be neglected, provided s is so small that $U_2 \longrightarrow U_1$. With distributed suction, this condition certainly holds, U_2 differing from U_1 by less than one per cent for any typical slot width and velocity gradient. In the remaining part of the discussion, therefore, we shall assume that $U_2 \simeq U_1$, and, consequently, that the only momentum change at the slot is that due to (*a*) above, namely, to withdrawal of fluid at the slot. Thus, at section 1 we have

$$M_1 = \rho \int_0^\infty u_1 (U_1 - u_1)\, dy = \rho \left[\int_0^{y_s} u_1 (U_1 - u_1)\, dy + \int_{y_s}^\infty u_1 (U_1 - u_1)\, dy \right].$$

But the first integral in the bracket represents the momentum loss associated with the part of the boundary layer extracted at the slot, and hence, at section 2

$$M_2 = \rho \int_{y_s}^\infty u_1 (U_1 - u_1)\, dy,$$

so that, by difference,

$$M_1 - M_2 = \rho \int_0^{y_s} u_1 (U_1 - u_1)\, dy,$$

or, since, by definition, the corresponding momentum thicknesses are

$$\theta_1 = \frac{M_1}{\rho U_1^2}, \qquad \theta_2 = \frac{M_2}{\rho U_2^2},$$

we have, on the above assumption that $U_2 \simeq U_1$,

$$\theta_1 - \theta_2 = \int_0^{y_s} \frac{u_1}{U_1}\left(1 - \frac{u_1}{U_1}\right) dy,$$

which may be written alternatively as

$$\frac{\theta_2}{\theta_1} = 1 - \int_0^{y_s/\theta_1} \frac{u_1}{U_1}\left(1 - \frac{u_1}{U_1}\right) d\left(\frac{y}{\theta_1}\right). \quad . \quad (5)$$

Finally, the suction quantity Q per unit length of slot is clearly

$$Q = \int_0^{y_s} u_1 dy,$$

or, in the conventional, non-dimensional, form,

$$C_Q = \frac{Q}{U_0 c} = \frac{U_1}{U_0}\frac{\theta_1}{c} \int_0^{y_s/\theta_1} \frac{u_1}{U_1} d\left(\frac{y}{\theta_1}\right), \quad . \quad (6)$$

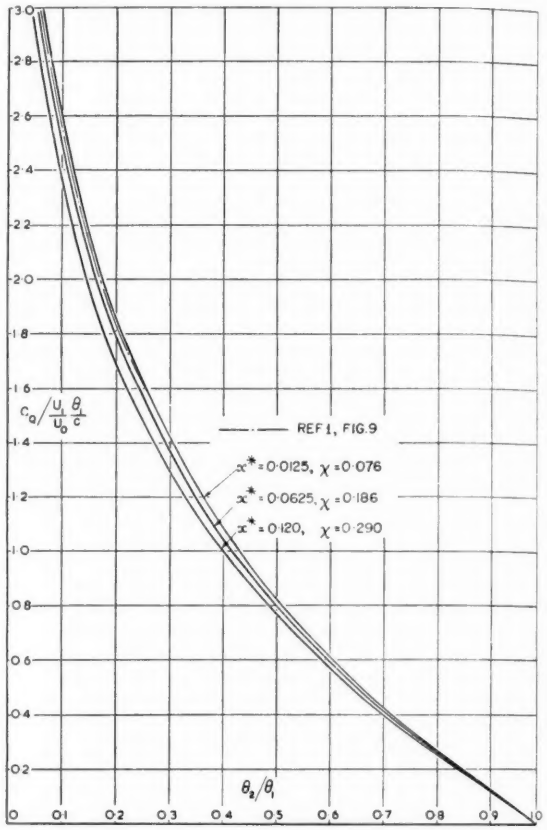

FIGURE 2. The quantity $C_Q \Big/ \left(\frac{U_1}{U_0}\frac{\theta_1}{c}\right)$ as a function of θ_2/θ_1.

where U_0 is the free stream velocity and c the wing chord.

It will be seen that Equations (5), (6) are precisely the results obtained by Lachmann, except that he defines C_Q in terms of the velocity U_1. Thus, from (5), (6)

$$C_Q \Big/ \left(\frac{U_1}{U_0}\frac{\theta_1}{c}\right)$$

may be tabulated as a function of θ_2/θ_1, given the velocity profile $u\,(y)$.

In Reference 1, a single curve is shown for the foregoing relation which, although it is not stated explicitly, appears to refer to the Blasius profile. It is of some interest, therefore, to consider how the streamwise pressure gradient may affect the result, since, in general, one would expect a family of such curves, each curve relating to the velocity profile appropriate to the local pressure gradient. This extension of the calculations is presented in Fig. 2. The relevant boundary layer profiles are those obtained by Howarth[3] for the linear velocity distribution given by Equation (3) (b_1 positive). That is to say,

$$\frac{u}{U} = f\left(\frac{y}{\theta}\right) = f\left(\frac{2x^{*\frac{1}{2}}\eta}{\chi}\right), \quad . \quad . \quad (7)$$

where $x^* = \frac{b_1 x}{b_0}$, $\eta = \frac{1}{2}(b_0/(\nu x))^{\frac{1}{2}} y$, $\chi = (b_1/\nu)^{\frac{1}{2}}\theta$, whence the numerical solution of (7) for any values of x^* and χ follows immediately from Tables II and III of Ref. 3.

From Fig. 2 it will be observed that, contrary to what

might be expected, the curves of quantity differ very little with change in the flow conditions, even to the point of separation ($x^* = 0{\cdot}120$). In practice, of course, the layer is so controlled that the velocity distribution $u(y)$ never departs appreciably from the Blasius profile—at incidences near zero lift, for example, it has been found to oscillate, as pointed out in Refs. 1, 2, between approximately the asymptotic form on the downstream side of a slot to the Blasius shape on the upstream side—so that, within the relevant limits, the relation between Equations (5), (6) is expressible with satisfactory accuracy by a single curve. This conclusion is based not only on the assumption of Equation (3), which is, nevertheless, a very good approximation over the small interval between two adjacent slots, but also on results (not recorded in Fig. 2) from boundary layer measurements by Schubauer[4] and von Doenhoff[5].

There is one other point, which should not be overlooked, in connection with the boundary layer criteria referred to at the beginning of this note. These, it seems clear, correctly represent the conditions which determine the maximum length of "free" flow between consecutive slots, provided, obviously, that there is no tendency to separation within an interval. But this may very well be the case over the rear part of an aerofoil, even at the low lift coefficients associated with flight conditions appropriate to extensive laminar flow. For example, in some relevant calculations performed recently on a family of low drag aerofoils, which varied in thickness from zero to 20 per cent of the chord, the author found that, although the boundary layer over the slotted part of the upper surface was at first normal in character, *i.e.* remained laminar and stable from the lower to the upper critical Reynolds number, it displayed, nevertheless, a velocity profile which steadily degenerated into the form indicative of separation, and a point was reached, well before the trailing edge, at which this condition supervened, despite the fact that the lift coefficient was approximately 0·15 in each case. This failure of the laminar layer to withstand a given adverse pressure gradient over a certain proportion of the chord may clearly be avoided by reducing the slot spacing or, in other words, by postulating a lower value for the Reynolds number immediately upstream of a slot. In the calculations to which we have referred, the development of the boundary layer was obtained by the method of Ref. 6, and the value of m, as there defined, was arbitrarily limited to 0·06. It is quite clear, therefore, that occasions can arise when some alternative end condition must be adopted in place of that for transition. Reduction of the slot spacing would seem to be the obvious choice.

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SOME OBSERVATIONS ON DR. COLEMAN'S COMMENTS

DR. G. V. LACHMANN, F.R.Ae.S.

THE METHOD referred to in Dr. Coleman's notes was developed with the collaboration of my colleague Mr. J. B. Edwards of Handley Page Research Department. The purpose was to obtain a rational estimate of suction quantities and suction distribution, linked up with measurements of boundary layer profiles and suction quantities on wind tunnel models, and also to assess the effect of a certain degree of roughness of the order to be expected on actual wings. Existing theoretical methods ignore roughness which, however, is a most important parameter not only in wind tunnel tests, but also in flight at higher values of the unit Reynolds number; surface roughness obviously limits the intensity of suction which can be applied at a spanwise suction strip.

It was intuitively assumed that the removal of fluid by suction was equivalent to cutting off the lower portion of the boundary layer profile at the upstream edge of the suction strip and that a rapid re-adjustment of the boundary layer profile within a short distance took place. The momentum thickness θ_2 of this new profile is less than θ_1 in view of the loss of momentum contained in the removed part of the fluid.

I doubt whether Dr. Coleman's approach reinforces this assumption substantially because in the first part of his analysis he introduces a debatable assumption.

The second part of his deductions where the change of momentum is attributed solely to the withdrawal of fluid is identical with our own assumptions and therefore leads to the same results.

The method has been utilised for the design of suction surfaces which were tested in free flight, and with the spacing between discrete suction strips which we adopted it was never observed that the velocity profiles degenerated to such an extent that separation took place between the strips before transition occurred, in fact, separation never took place, and transition could be prevented by suitable adjustment of suction. This does not exclude the possibility that with wider spacing of the suction strips, separation might eventually occur.

Wuest[1] [2] has drawn attention to the destabilising effect of suction through discrete suction strips and has given a method for calculating the periodic boundary layer flow and its stability in the two-dimensional case of equally spaced suction slots. Goertler has suggested to the writer that secondary instability may occur between too widely spaced suction strips due to flow concavity.

One should, therefore, not attempt to obtain a better economy by concentrating stronger suction at fewer discrete slots or suction strips spaced at greater intervals even on very smooth surfaces. The opposite method, *i.e.* more closely spaced suction strips with relatively weaker suction at each strip, is the preferable one. This applies particularly in the case of swept wings where cross flow exists and where the closest possible approach to distributed suction becomes essential.

However, in this case distribution of suction intensity must be determined with the aim of avoiding critical cross flow Reynolds numbers (Owen criterion).

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Graduates' and Students' Section

THE following comment on Mr. A. T. Hill's letter in the February Journal on engineers has been received from Wing Commander H. R. P. Patterson, O.B.E., M.A.:

Dear Sir,

May I venture to comment on Mr. A. T. Hill's letter in the February 1957 number of the Journal: not, I hasten to add, on matters of policy but purely on the lesser issue of categorical definitions. What, for instance, is a Captain?

There are, as is well known, Captains of aircraft and of bands, Captains of cricket and Captains of industry. There are Group Captains, Salvation Army Captains, and chaps in the local called "Cap."

There are sisters. Nursing Sisters (strangely enough both male and female), Staff sisters, half sisters, Beverley Sisters, American Sisters and unfortunate Sisters.

So also are there engineers in great variety. Production engineers, maintenance engineers, sanitary and civil, structural and surgical, automobile and atomic, mechanical and, for all I know, furnace and crematoric engineers.

Then why be stuffy about technicians? In the R.A.F. a Halton Apprentice is expected after a three year Course to graduate as a Junior Technician having obtained his O.N.C. as a hall-mark. With experience and by continuing his studies he may (and probably will) rise to Senior Technician and eventually to Master Technician Status. Thus there is a suitable ladder from technician to technologist (a category which Mr. Hill does not mention and to which some of the specialisations he mentions, *e.g.* aerodynamicist, may perhaps be appropriate). I am sure Mr. Hill is right in saying that the R.A.F. has its own ideas about technician standards and that these do not always agree with industry. In fact, for every one of the numerous R.A.F. trades the status of technician is defined in terms of practical ability and educational attainment, both of these requisites being tested by examination before the individual is given the rank and pay. Moreover the standards for each trade are in fair mutual agreement, even allowing for such widely divergent trades as occur in the mechanical and electrical fields. Even the dental and cookery trades have their technician level clearly defined. I think I am right in saying that there is no such rigorous definition of technicians in industry and therefore any equation between Service and Civilian standards is difficult.

Perhaps the work now proceeding at the City and Guilds of London Institute under the direction of Sir Roy Fedden may result in some clarification and a Technicians Certificate appropriate both to civilian and Service personnel.

Yours faithfully,

H. R. P. Patterson.

Summer Party

TICKETS are now available for our summer party for students, graduates and their friends. It will be at 4 Hamilton Place on Friday 21st June from 8 p.m. to 11.30 p.m.

As with our pioneer party last year, the emphasis will be on informality. Once again we shall be providing a complete evening's entertainment at the very low all-in charge of 5s. a head. This includes free drink—wine, beer and soft drinks—as well as food. Not even the poorest student need fear that, once inside the door, he will have to dip into his pocket to still the thirst and hunger of himself and girl friend.

There will be games, dancing and, we hope, a skiffle group. Everything is being done to make this evening as good value as possible. Committee members, aided by wives and girl friends, will act as sandwich makers, disc-jockeys, barmen, etc. Any members who are willing to come early and help with the organisation will be most welcome.

If you would like to come—and we hope you will—please ask any committee member for tickets or write to:—

P. D. Stewart,
12 The Grove,
Isleworth,
Middlesex.

Please apply for tickets early; last year we had to turn down more than thirty late requests to avoid 4 Hamilton Place being over-crowded on the night of the party.—J.R.C.

Graduates' and Students' Section—Visits

R.A.E. ROCKET PROPULSION DEPARTMENT. As mentioned briefly in an earlier Journal, we have been granted a visit to the Rocket Propulsion Department of the Royal Aircraft Establishment at Westcott, Bucks.

The visit was delayed by the petrol crisis, but we now have it arranged for Wednesday 10th July in the afternoon. A coach has been hired, which will leave Central London at about 11.30 a.m.

Would those interested please write to the Hon. Visits Secretary, Mr. N. K. Benson, 14 Wakering Road, Barking, Essex.

Lecture

MEMBERS are reminded that the Section's last lecture for this Session is on 15th May, in the Library, 4 Hamilton Place, at 7.30 p.m. Mr. W. H. Stephens, M.Sc., A.F.R.Ae.S., Head of the Guided Weapons Department at R.A.E., will lecture on "Guided Weapon Research and Development." Members will need no encouragement to attend one of the far too few expositions of this art.

THE LIBRARY
Reviews

VISCOUS FLOW THEORY. I.—LAMINAR FLOW. *Shih-I Pai. Van Nostrand, Princeton, N.J., 1956. 384 pp. 45s.*

This is a rather remarkable book in that it covers a far wider range of topics in the theory of viscous flow than any other single book that this reviewer, at least, has seen. The author certainly may be congratulated on this achievement and also on his sound knowledge of the literature of the subject which is evidenced in the list of authors he cites. At the same time he has, very wisely, made no attempt to give exhaustive bibliographies and has contented himself with only those references which he felt were necessary to his own account of the subject; but he also adopted a very useful little device, which could well become standard procedure for similar books, of asterisking references which themselves contain full bibliographies.

The first two chapters contain general discussions of the physical properties of gases and set the tone of the whole book, by which is meant primarily that the treatment is extremely concise. The particular virtue of the book, however, is that this conciseness has not led to serious incompleteness, or inaccuracy or lack of vigour. I often tried to catch the author out, as I read the book, by saying "Oh, but you've forgotten such-and-such a special case" only to find that the special case was disposed of, probably in one sentence, but nevertheless covered, a little further on in the text.

Further chapters follow naturally from the third which establishes the Navier-Stokes equations. No concessions are made to sloth: all possible flows—compressible, heat conducting, unsteady—come within the author's grasp, the main distinctions being drawn between two- and three-dimensional and axi-symmetric flows. Three chapters I found particularly welcome, especially as their subject matter is not in the conventional list for books on this topic. Chapter VI discusses some general properties of the Navier-Stokes equations, and this is taken up again in the last Chapter of all which is an account of viscous compressible flow as revealed by linearising the equations. And Chapter VII on very slow motions is sufficiently short not to unbalance the book, but is there all the same as a sort of hors d'oeuvres, before the main bulk of boundary-layer theory which extends over 216 pages of the full 376 pages of text.

If the book has a weakness it is that it deals exclusively with theory: one can hardly recall any appeal to experiment or even simple observation. Certainly the author tells us, in the title, not to expect such things but even so the serious reader may well ask "But what has all this got to do with the flow of real fluid?" Even an occasional remark about what happens in practice would have been valuable. But if theory is what you want—and very many different kinds of people nowadays *do* want it in a highly condensed form—this book should find its way on to your shelves.—BRYAN THWAITES.

THE ANALYSIS OF STRUCTURES. *N. J. Hoff. Wiley, New York; Chapman and Hall, London, 1956. 493 pp. Diagrams. 76s.*

This volume is a major work and eminently worthy of one of the foremost teachers and researchers in the field of Structural Analysis. It combines in a striking manner the lucidity of the teacher with the vitality of the original investigator.

At the beginning of the Preface the author states "Many students of engineering consider the analysis of structures a rather boring subject. They do not understand the justification of the assumptions made, and they get tired of memorising scores of unrelated formulas, rules and procedures." A brief study of this book is sufficient to show the author's concern to present the subject as "a logical and unified theory based on a small number of first assumptions,"—and yet not to be dull. These two objectives the author attains by basing everything he does on the two allied concepts of work and energy.

The book is divided into four main sections of roughly equal length, entitled: "The Principle of Virtual Displacements, The Minimum of the Total Potential, The Calculation of Buckling Loads, Complementary Energy and Least-Work Methods," and each contains a large number of worked problems drawn from many different fields.

Although the book is based on lectures given by the author to first year graduates in aeronautical, civil, and mechanical engineering, the first half of it should be of great value to third year undergraduates, and, to quote the author, "the presentation is simple enough to allow a practicing engineer, who is a little rusty on mathematics and mechanics, to read the book by himself, without advice from a teacher." For such a one the second half of the book should be particularly useful. An interesting feature of the book is the replacement of the normal practice of giving references at the bottom of a page or at the end of a chapter by an Appendix which is arranged as a historical commentary. The book also contains a certain number of examples of the textbook kind, and these, too, are all grouped together in an Appendix.

The book is beautifully produced and deserves to have a place on the shelves of many.—D. M. A. LEGGETT.

NEW ZEALANDERS WITH THE ROYAL AIR FORCE. *Volumes I and II. Wing Commander H. L. Thompson. Dept. of Internal Affairs, Wellington, 1953 and 1956. 408 pp. and 483 pp. Illustrated.*

These are the first two volumes of this part of the Official War History and as such are reference works rather than popular or over-glamourised versions of war stories.

The first volume deals with events in the European theatre between September 1939 and December 1942; the second continues the same record between January 1943 and May 1945. Activities in other theatres will be covered by a later work.

It is difficult to appreciate the size of New Zealand's participation in the war in the air until one reads that nearly 11,000 New Zealanders served with the Royal Air Force. Those who served with the Royal New Zealand Air Force made the numbers up to over 55,000 which is a very high percentage of the small population. New Zealanders seemed to find their way into every sphere of operation.

Wing Commander Thompson has divided both volumes into chapters dealing with the different types of operation within the time limits of the volume. This gives anyone reading the books from cover to cover an impression of repetition. While this could be a criticism if the subject work were a novel, such division obviously simplifies reference.

The Appendices to Volume I include a list of the

aircraft in use by both sides at the beginning of the war, and looking back over what seems a short distance in time one is a little shaken to be reminded once again of the almost alarming rate of development of aircraft, engines, and equipment. In fact this is a constantly recurring reaction. As another example, in the chapter dealing with the exploits of Bomber Command the following words appear "Beginning with a raid by 600 Lancasters and Halifaxes against Kiel on 23rd July, British bombers attacked eighteen German towns during the next five weeks, dropping 30,000 tons of bombs." For the tremendous sums of human effort needed to sustain raids on such a scale the total of 30,000 tons seems nowadays to be somewhat out of proportion when compared with the effect of one hydrogen bomb.

Such thoughts are probably responsible for a reaction akin to nostalgia—maybe for a war as uncomplicated as Spitfires and T.N.T.—maybe for the more personal side. It could well be that Wing Commander Thompson has written a chapter in the record of the last major conflict in which the individual plays a vital role. His books abound with stories of the skill, endurance, and courage of individuals going to war in a very personal sort of way. With the continued emphasis on guided missiles it appears as though any future major war will be a far more impersonal affair calling for endurance and fortitude from the population as a whole.

The author and his helpers are to be recommended for a really thorough job of research, reading and extracting from all the files and official records. The result is a comprehensive, detailed and well annotated reference work. —B. CORNTHWAITE.

DAS BUCH DER DEUTSCHEN FLUGGESCHICHTE: VOLUME I. *Peter Supf. (History of German Aviation) (in German). New enlarged edition. Drei Brunnen Verlag, Stuttgart, 1956. 599 pp. Illustrated. DM.39.*

This is the first volume of a comprehensive trilogy and covers up to 1912. It is an expurgated edition of the 1935 edition, and deals solely with aviation. Lighter-than-air aeronautics and the Austrian development have, unfortunately, been neglected in spite of their direct influence upon German aviation. This renders the presentation rather unbalanced. It is unfortunate, too, that the new edition reproduces the many splendid photos much less clearly than the original one.

Several minor criticisms of omission can be made but they are practically unavoidable in any work of this nature. They cannot distract from the impression that Supf has written a magnificent book of permanent and authoritative value, and anyone interested in aviation history will look forward to the two following volumes.

Frank Smith complains that this work would have been so much more useful if it had been written in English. In sympathy with this appraisal, one might express regret that there is no equivalent work on British aeronautics, and that most probably there will be none. Supf's new edition has been made possible by financial aid from the Continental Rubber Works, in a country in which aviation is practically non-existent.—A. R. WEYL.

ENGINEERING STRUCTURAL FAILURES. *Rolt Hammond. Odhams Press, London, 1956. 224 pp. Illustrated. 25s.*

Almost the whole of this book deals with civil engineering aspects, surveying the causes and results of failures in earthworks, dams, harbour works, buildings, bridges and tunnels. The last two chapters, however, may be of interest to aeronautical engineers; these discuss failures in welded structures of steel or light alloys, modern methods of testing materials, ranging from X-ray and electronic developments to aircraft pressure tanks, and lessons learnt from structural failures.

COLLECTED WORKS OF THEODORE VON KARMAN. *Four Volumes 1902-1951. Butterworths, London, 1956. 1,838 pp. Illustrated. £14 10s.*

The Journal for March 1956 contains a review of "Selected Papers on Engineering Mechanics," written by students and associates of Dr. von Kármán to commemorate his 70th birthday, and a personal tribute to him by Captain Pritchard.

From the same publishers we have now the "Collected Works of Theodore von Kármán" in four volumes, covering respectively the periods 1902-1913, 1914-1932, 1933-1939, 1940-1951, with a Foreword by Dr. Hugh Dryden.

In the first two volumes, the papers are nearly all written in German, but the third and fourth volumes, written since Dr. von Kármán went to live in California in 1930, are almost entirely in English. The 111 papers contained in these volumes cover a very wide range of subjects and are by no means all the papers he has written, but they are, of course, an invaluable collection of classic papers, well printed and produced.

ELEMENTS OF PURE AND APPLIED MATHEMATICS. *Harry Lass. McGraw-Hill, New York, 1957. 491 pp. 56s. 6d.*

This book is intended for the undergraduate and graduate student and is written by a mathematics lecturer and research specialist at the Jet Propulsion Laboratory of the California Institute of Technology. The "Applied Mathematics" in the title seems misleading, for the subjects covered, as listed in the Contents, are linear equations, determinants and matrices; vector analysis; tensor analysis; complex-variable theory; differential equations; orthogonal polynomials, Fourier series and Fourier integrals; the Stieltjes integral, Laplace transform and calculus of variations; group theory and algebraic equations; probability theory and statistics and real-variable theory. Each chapter contains a large number of worked examples and additional problems.

LE BOURGET. *Laurent Moncany (in French). Club du Beau Livre de France, Paris, 1956. 171 pp. Illustrated.*

This book, which is written in praise of a past era of aviation, leaves the impression that the author almost regrets the growth of other airports as against Le Bourget, since it leads to the comparative eclipse of his spiritual home. A warning must be given against numerous inaccuracies in this book, which prevent it being used safely for serious reference. The first page of illustrations includes a photograph bearing a caption describing the Airport Building and Meteorological Office about 1925 with a Handley Page of Imperial Airways flying overhead. In fact the aeroplane is Short Scylla or Syrinx, which must also alter the date of the photograph by some years. On page 33 the Farman "Jabiru" is mentioned as a three-motored aircraft; while it was at one stage in its remarkable career three-motored it was in its four-motored stage when used by C.I.D.N.A. The details given of the early routes connecting Paris with Switzerland appear incomplete, since while the Geneva route is thoroughly covered the early operations on the Bâle and Zürich route are hardly mentioned, in spite of the difficulties which were encountered—not always successfully—in its operation. A

misprint on page 53 turns the Handley Page which opened the service from Cricklewood to Le Bourget, with eleven passengers, into a two-seater!

The history of Le Bourget airport is covered from its start until 1956, with chapters on the operating companies, air mail, record breaking flights, airport equipment, and latest administrative and technical development. The real purpose of the book seems however to be contained in the final pages entitled " Réflexions."

ILLUSTRIERTE TECHNISCHE WORLERTUCHER. *German-English-French-Italian. Vol. XVII. Aeronautics. By Alfred Schlomann. R. Oldenbourg, Munich, 1956. 292 pp. and 108 pp. of illustrations and 337 pp. Index. DM 64.*

The Germans have performed a service for the international aeronautical field by bringing up-to-date a 1932 quadrilingual dictionary.

It is done with the customary Teutonic thoroughness and comprises tables of contents in four languages, divided and subdivided into subject sections; the main dictionary similarly divided, an illustrated section with each illustration bearing the reference number from the main dictionary and, finally, the four separate alphabetical indexes to the languages—conveniently thumb-indicated.

There are, one supposes, omissions but only use will find them out and in the meantime the dictionary fills the proverbial " long felt want."—F.H.S.

THEY SHALL NOT PASS UNSEEN. *Ivan Southall. Angus and Robertson, Sydney and London, 1956. 214 pp. 26 Illustrations. 16s.*

Only those whose daily task is to meet the sea in all its sudden and violent changes of mood are likely to remain unmoved by the stories told by Ivan Southall.

The author states in his Preface that this is the true story of some of the exploits of a community of airmen who flew Sunderland flying boats in the Battle of the Atlantic. He has selected No. 461 Squadron, Royal Australian Air Force because he served with it as a Captain of one of these formidable aircraft and because their work was typical of that which was carried out by many units from many countries whose purpose was to defend the sea routes to Britain.

His task is a difficult one. He has tried to give a picture of the ebb and flow of the fortunes of the U-boat on the one hand and the united effort by Coastal Command and the Royal Navy on the other. He has avoided the almost impossible task of writing a history in the true sense but instead has tried to illustrate the Squadron's work and the spirit of its crews and of its Commanding Officers from the time of its formation on Anzac Day 1942 until its last operational sortie on 18th June 1945.

The story is built up in a rather disjointed manner from incidents in which the Squadron's aircraft took part with varying degrees of success.

The Bay of Biscay is the setting of many of the stories and these are told with a vividness which is unusual even for a war narrative; they are well worth reading, although some are not suitable for bed-time reading, such as the tales of hazardous " landings " in appalling weather in the open sea to rescue a ditched crew in a dinghy and a description of the fight to save a flying boat which has broken adrift from its moorings in a gale of one hundred and twenty knots.

This book achieves the very limited objects stated by the author in his Preface and incidentally fills a gap in the literature about World War II which is rather overburdened with stories of the more glamorous operational Commands. It emphasises the determination of men to take on all risks in seeking out and destroying the most hated of all naval weapons, the enemy submarine. It also lifts a corner of the curtain of modesty with which Australians surround their deeds in war time. These flying boat crews and those of the other R.A.A.F. Squadron, No. 10, should be far better known for their efforts in the defence of Britain.

The endless, plodding patrols, so boring and yet, sometimes, all too suddenly turned into life and death struggles with enemies varying from vicious and damaging storms to heavy and concerted attacks from massed fighters or surfaced U-boats brought out the qualities in these men which justified the claim on their Squadron Crest, " They shall not pass unseen."—A.S.C.L.

MOON SQUADRON. *Jerrard Tickell. Allan Wingate, London. 204 pp. 13s. 6d.*

In " Moon Squadron " Jerrard Tickell sets out to tell the story of how allied agents were delivered and picked up by moonlight in enemy-occupied countries during the Second World War.

Here was a chance to write a book of exceptional interest, despite inevitable security restrictions. The author starts off well but the reader is confused because the narrative jumps backwards and forwards between 1942, 1943 and 1944. This is most irritating and spoils the build up of drama. Individual incidents are well described but, towards the end, the book degenerates into the style of an official history.

There are unfortunately several inaccuracies which should not have occurred. The author describes the picking-up of a message by means of a hook mounted beneath a Lysander in 1944 as if it were a new idea. This hook was standard equipment on the aircraft when introduced for Army Co-operation duties in 1939 and the hook had been in use for many years before that in the R.A.F.

Furthermore, one wonders whether the statement is really accurate that there was no traceable breach of security from Tempsford, relating to the type of activity carried out there. The reviewer on several occasions noticed with interest Lysanders painted black, with telltale ladders fixed to their sides, parked a very short distance from the L.N.E.R. main line to Scotland, which passes the aerodrome. The functions of such aircraft were obvious and the source of much speculation among those who saw them.

From the author of such books as " Odette," " Appointment with Venus " and others, this book is a little disappointing and does not really do justice to a gallant company of R.A.F. crews whose skill and daring is matched by the tremendous courage of the agents, both men and women and of the Reception Committees.—A.S.C.L.

PROPERTIES OF COMBUSTION GASES. *System*: C_nH_{2n}—*Air. Vols. I and II. Prepared by the Aircraft Gas Turbine Development Department of the General Electric Company. McGraw-Hill, New York, 1955. 1054 pp. £28 2s. 6d.*

Apart from the Introduction, these volumes consist entirely of tables, which provide accurate information on the thermodynamic properties and behaviour of the air-breathing combustion engine under wide ranges of operating conditions. The tables are applicable to the combustion gases of any hydrocarbon fuel with a hydrogen to carbon ratio of two, independently of the fuel's chemical make-up or heating value. The functions tabulated in Volume I are enthalpy, entropy, mean molecular weight, density, sonic velocity, heat capacity and two non-ideality

coefficients. The independent variables are temperature (from 600° to 5,000°R in 100°R increments), pressure and equivalence ratio. Volume II lists the equilibrium chemical composition of the combustion gases in terms of the molfractions for temperatures above 2,500°R for the same independent variables as in Volume I. The primary source data for both volumes are taken from the National Bureau of Standards—American Petroleum Institute Publications.

HYDRODYNAMICS. *Hugh L. Dryden, Francis P. Murnaghan and H. Bateman. 634 pp. Diagrams. $2.50.*

THE THEORY OF THE BROWNIAN MOVEMENT. *Albert Einstein. 122 pp. $1.25.*

THE PRINCIPLES OF MECHANICS. *Heinrich Hertz. 274 pp. $1.75.*

ASYMPTOTIC EXPANSIONS. *A. Erdelyi. 108 pp. $1.35.*

EXPERIMENT AND THEORY IN PHYSICS. *Max Born. 44 pp. $0.60.*

All published by Dover Publications, Inc., New York.

Five more books in the Dover Publications series of reprints of scientific classics have appeared. *Hydrodynamics* is a republication of the report of the Committee on Hydrodynamics, Division of Physical Sciences (Bulletin 84 of the National Research Council), first published in 1932. The second book is a reprint from the translation first published in 1926, and the third is reprinted from the translation of 1899 of the original German edition of 1894. *Asymptotic Expansions* is based on a course of lectures given at the California Institute of Technology in the autumn of 1954. The fifth book is an address by Professor Born to the Durham Philosophical Society and the Pure Science Society, King's College, Newcastle, in May 1953.

FATIGUE OF METALS. *Published by the Institution of Metallurgists, London, 1956. 148 pp. Diagrams. 25s.*

The ninth Refresher Course arranged by the Institution of Metallurgists was held at Llandudno in October 1955. Five lectures concerned with the general problems of "Fatigue of Metals" were given and were followed by discussions, which unfortunately are not included in this volume of the proceedings. The five papers presented are: Fundamental Considerations on the Fatigue of Metals by J. Holden; The Effect on Fatigue of Notches, Surface Finishes, etc., by G. Forrest; The Structural Aspects of Aircraft Fatigue by P. B. Walker; Corrosion Fatigue by R. B. Waterhouse; and Effect of Temperature on Fatigue Properties by P. H. Frith.

ATOMIC WEAPONS AND EAST-WEST RELATIONS. *P. M. S. Blackett. Cambridge University Press, 1956. 107 pp. 8s. 6d.*

Professor Blackett chose this subject when invited by Trinity College, Cambridge, to give the Lees Knowles Lectures on Military Science in the spring of 1956, and this book is the published version of the lectures. The three lectures were: Western Military Policy; The Atomic Arms Race 1945-55; and Retrospect and Prospect. The book is naturally a controversial one, and the author takes the view that much of the extreme anxiety in the West has been due to faulty military and political thinking.

Additions to the Library

**Aeroplane. The Aeroplane* DIRECTORY 1957. Temple Press. 1957.

L'Armee de l'air. MANUEL DU GRADE DE L'ARMEE DE L'AIR. 21st edition. Charles-Lavauzelle. 1939.

Batchelor, G. K. and Proudman, I. THE LARGE-SCALE STRUCTURE OF HOMOGENEOUS TURBULENCE. Phil. Trans. 949. Royal Society. 1956.

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Reports

AERODYNAMICS

Boundary Layer

The three dimensional laminar boundary layer flow about a yawed ellipsoid at zero incidence. J. A. Zaat. N.L.L. Report F. 165 included in N.L.L. Transactions Vol. XX. (1955).

Using Timman's two-parameter method for three-dimensional laminar boundary layers the velocity distribution in the laminar boundary layer of a yawed ellipsoid at zero incidence will be calculated. The momentum equations in streamline direction and perpendicular to this direction can be reduced to a set of quasi-linear first order partial differential equations. The initial conditions necessary for solving the system of differential equations are determined from the behaviour of the differential equations in the stagnation point.—(1.1.1.1).

On possible similarity solutions for three-dimensional incompressible laminar boundary layers. III—Similarity with respect to stationary polar coordinates for small angle variation. H. Z. Herzig and A. G. Hansen. N.A.C.A. T.N. 3890. (*January* 1957).

Approximate solutions are obtained describing main stream flows confined to regions of small angle variation over flat surfaces for three-dimensional, laminar, incompressible, thin boundary layer flows having similarity with respect to stationary polar co-ordinate systems. The solutions, summarised in a table, include accelerating or decelerating flows and stagnation-point, spiral, or circular flows.—(1.1.1.1).

Compressible Flow

See also Testing and Instruments

A theoretical investigation of the drag of generalized aircraft configurations in supersonic flow. E. W. Graham et al. N.A.C.A. T.M. 1421. (*January* 1957).

In supersonic flight, unconventional arrangements of wings and bodies may offer advantages in the form of drag reduction. The methods are considered for determining the pressure drag for such unconventional configurations, and to consider a few of the possibilities for drag reduction in highly idealised aircraft.—(1.2.3.1).

Method for calculating effects of dissociation on flow variables in the relaxation zone behind normal shock waves. J. S. Evans. N.A.C.A. T.N. 3860. (*December* 1956).

Generalised expressions and charts are presented for the temperature, pressure, density, and flow velocity behind a shock wave that depend on the shock Mach number, the initial state of the gas, and an enthalpy parameter. The variation of this parameter behind the shock is related directly to the variation of the degree of dissociation.—(1.2.3.2).

Aerodynamic characteristics of a circular cylinder at Mach number 6·86 and angles of attack up to 90°. J. A. Penland. N.A.C.A. T.N. 3861. (*January* 1957).

Pressure-distribution and force tests of a circular cylinder have been made in the Langley 11 in. hypersonic tunnel at a Mach number of 6·86, a Reynolds number of 129,000, and angles of attack up to 90°.—(1.2.3).

Experimental determination of the range of applicability of the transonic area rule for wings of triangular plan form. W. A. Page. N.A.C.A. T.N. 3872. (*December* 1956).

Further knowledge regarding the range of applicability of the transonic area rule has been gained by the results of an experimental investigation at transonic speeds of the zero-lift drag rise of a family of related wings of triangular plan form in combination with a cylindrical body.—(1.2.3).

The similarity rules for second-order subsonic and supersonic flow. M. D. Van Dyke. N.A.C.A. T.N. 3875. (*January* 1957).

The similarity rules for linearised compressible flow theory (Göthert's rule and its supersonic counterpart) are extended to second order. It is shown that any second-order subsonic flow can be related to "nearly incompressible" flow past the same body, which can be calculated by the Janzen-Rayleigh method.—(1.2).

Oblique-shock relations at hypersonic speeds for air in chemical equilibrium. W. E. Moeckel. N.A.C.A. T.N. 3895. (*January* 1957).

Oblique-shock relations for air in chemical equilibrium have been calculated for flight velocities up to 25,000 feet per second at altitudes up to 200,000 feet. Results show that those shock parameters which are functions only of Mach number normal to the shock for an ideal gas are strongly influenced by flight altitude (initial conditions), as well as normal Mach number when dissociation takes place.—(1.2.3.2).

Control Surfaces

See also Wings and Aerofoils

Wind-tunnel investigation of an external-flow jet-augmented slotted flap suitable for application to airplanes with pod-mounted jet engines. J. P. Campbell and J. L. Johnson. N.A.C.A. T.N. 3898. (*December* 1956).

A wind tunnel investigation has been carried out to determine the characteristics of an external flow jet-augmented slotted flap which appears suitable for application to aeroplanes with pod-mounted jet engines. The investigation included tests of an aspect ratio 6 unswept wing and of a model of a swept-wing jet transport or bomber over a momentum coefficient range up to about 8. The jet transport or bomber model had a 30° swept-back wing with an aspect ratio of 6·62.—(1.3.4).

Fluid Dynamics

The flow at the mouth of a Stanton Pitot. A. Thom. R. & M. 2984. (1956).

An arithmetical calculation is made of the flow at the mouth of a Stanton Pitot as the Reynolds number tends to zero. A stationary eddy is found under the lip of the Pitot. A figure is found for the height of the effective centre of the Pitot rather greater than the experimental value determined by Sir Geoffrey Taylor.—(1.4).

Internal Flow

Tests on rough surfaced compressor blading. R. C. Turner and H. P. Hughes. C.P. 306. (1956).

Six stages of medium stagger free vortex blading, with rough surface finish, were tested in the N.G.T.E. 106 compressor. Overall characteristics were determined at various speeds and compared with those of similar blading with the conventional smooth finish.—(1.5.2.1).

Investigation of rotating stall in a single-stage axial compressor. S. R. Montgomery and J. J. Braun. N.A.C.A. T.N. 3823. (*January* 1957).

The rotating-stall characteristics of a single-stage axial-flow compressor were investigated. The number of stall cells and their propagation velocities were found with and without stator blades.—(1.5.2.1).

Loads

See also Wings and Aerofoils and Aeroelasticity

Some measurements of aerodynamic forces and moments at subsonic speeds on a wing-tank configuration oscillating in pitch about the wing midchord. S. A. Clevenson and S. A. Leadbetter. N.A.C.A. T.N. 3822. (*December* 1956).

Measurements are presented of the aerodynamic forces and moments acting on a wing-tank configuration, with or without fins, oscillating about the wing-root midchord. The reduced-frequency range was from 0·050 to 0·657, whereas the Mach number and Reynolds number range was from 0·18 to 0·75 and $0{\cdot}9\times10^6$ to $9{\cdot}5\times10^6$, respectively.—(1.6.3×2).

Theoretical calculation of the power spectra of the rolling and yawing moments on a wing in random turbulence. J. M. Eggleston and F. W. Diederich. N.A.C.A. T.N. 3864. (*December* 1956).

An analytical solution is derived for the power spectral density of the rolling- and yawing-moment coefficients of a wing subjected to random isotropic atmospheric turbulence. The theory considers the random variations of the turbulence in the spanwise as well as the flight-path direction. Horizontal, vertical, and side gust components are considered. Plots of the power spectra are presented.—(1.6.3).

STABILITY AND CONTROL

Recherche de définitions et de critères de divergence non oscillatoire au voisinage d'un régime permanent de vol. E. Billin. O.N.E.R.A. Note Technique No. 38. (1956).

L'expression usuelle " Stabilité statique " soulève certaines difficultés d'interprétation dans le cas d'un système à plusieurs degrés de liberté. Le point de vue retenu ici consiste à isoler, parmi les phénomènes consécutifs à une perturbation, ceux qui présentent un caractère non oscillatoire. Dans le cadre de l'approximation linéaire, seules les racines réelles de l'équation caractéristique régissant le système sont alors prises en considération.—(1.8).

On the use of the harmonic linearization method in the automatic control theory. E. P. Popov. N.A.C.A. T.M. 1406. (*January* 1957).

The use of harmonic linearisation as applied to the analysis of non-linear automatic control systems is considered. This approach, which has been proven in practical engineering applications, involves the replacement of a non-linear equation by a linear equation.—(1.8).

Experimental and predicted lateral-directional dynamic-response characteristics of a large flexible 35° *swept-wing airplane at an altitude of* 35,000 *feet. S. C. Brown and E. C. Holleman. N.A.C.A. T.N.* 3874. (*December* 1956).

Lateral-directional dynamic-response characteristics of a large flexible 35° swept-wing aeroplane at an altitude of 35,000 feet are presented. Frequency responses, transfer functions, and stability derivatives are evaluated from transient responses obtained from abrupt aileron or rudder inputs. The measured dynamic responses are compared with predicted responses for the aeroplane treated as both rigid and flexible.—(1.8.1.1×2).

Subsonic wind-tunnel investigation of the effect of fuselage afterbody on directional stability of wing-fuselage combinations at high angles of attack. E. C. Polhamus and K. P. Spreemann. N.A.C.A. T.N. 3896. (*December* 1956).

A wind tunnel study of the directional stability characteristics at high angles of attack of two wing-fuselage combinations has been conducted at subsonic speeds. The wings utilised were a 4 per cent thick unswept wing of aspect ratio 3·0 and a 6 per cent thick 45° swept-back wing of aspect ratio 4.—(1.8.1.2).

THERMO-AERODYNAMICS

Theory and design of a pneumatic temperature probe and experimental results obtained in a high-temperature gas stream. F. S. Simmons and G. E. Glawe. N.A.C.A. T.N. 3893. (*January* 1957).

The basic theory of pneumatic temperature probes and deviations from this basic theory in practical application are presented. Design requirements and operating considerations are discussed. Temperatures between 1600° and 4000° R were measured with an experimental probe in hydrocarbon combustion exhaust gases and compared with those measured by thermocouples and a line-reversal pyrometer. Reasonable agreement among the instruments was obtained.—(1.9.1×1.12).

WINGS AND AEROFOILS

An extension of Multhopp's method of calculating the spanwise loading of wing-fuselage combinations. J. Weber et al. R. & M. 2872. (1956).

A simple method is described for calculating the spanwise loading over wing-fuselage combinations. It is based on Multhopp's method, which is extended here to cover wings of finite thickness, large root chords compared with the body diameter and also swept wings. The method is restricted to wings of moderate and large aspect ratios (above about 2). The effect of different junction shapes above and below the wing in off-centre positions of the wing cannot yet be calculated.—(1.10.1.2).

Theoretical load distribution on a wing with vertical plates. J. Weber. R. & M. 2960. (1956).

The spanwise load distribution is calculated for wings with plates normal to the wing and parallel to the main stream, or inclined to it at a small angle. The calculations are made for configurations having minimum induced drag. The results are used to obtain an approximation for wings of any plan form (where the condition of minimum induced drag no longer applies) including wings with sweepback.—(1.10.1.2).

Turbulence in the wake of a thin airfoil at low speeds. G. S. Campbell. N.A.C.A. T.M. 1427. (*January* 1957).

Experiments have been made to determine the nature of turbulence in the wake of a two-dimensional aerofoil at low speeds. The experiments were motivated by the need for data which can be used for analysis of the tail-buffeting problem in aircraft design. Turbulent intensity and power spectra of the velocity fluctuations were measured at a Reynolds number of $1{\cdot}6\times10^5$ for several angles of attack. Total head measurements were also obtained in an attempt to relate steady and fluctuating wake properties.—(1.10.2.1 ×1.6.3).

Wind-tunnel investigation at low speeds to determine the effect of aspect ratio and end plates on a rectangular wing with jet flaps deflected 85°. *J. G. Lowry and R. D. Vogler. N.A.C.A. T.N.* 3863. (*December* 1957).

Results are given of an investigation of the effect of aspect ratio and end plates on the aerodynamic characteristics of wings with a jet flap deflected 85° and operating with momentum coefficients from 0 to 17·5. The wings were unswept rectangular N.A.C.A. 0012 aerofoil sections modified for jet flaps.—(1.10.2.2×1.3.4).

Wind-tunnel investigation of the aerodynamic characteristics in pitch of wing-fuselage combinations at high subsonic speeds. Taper-ratio series. T. J. King and T. B. Pasteur. N.A.C.A. T.N. 3867. (*December* 1956).

Aerodynamic characteristics are presented of wing-fuselage combinations having an aspect ratio of 4, a sweepback angle of 45°, and taper ratios of 0·3, 0·6 and 1·0. The tests covered a Mach number range from 0·4 to 0·95 at Reynolds numbers of 2,000,000 to 3,000,000 and an angle-of-attack range from −2° to 26°.—(1.10.2.2).

Investigation of the effectiveness of boundary-layer control by blowing over a combination of sliding and plain flaps in deflecting a propeller slipstream downward for vertical take-off. K. P. Spreemann and R. E. Kuhn. N.A.C.A. T.N. 3904. (*December* 1956).

An investigation was conducted in order to determine the effectiveness of blowing a jet of air over the flaps of a wing equipped with a 50 per cent chord sliding flap and a 25 per cent chord plain flap in deflecting a propeller slipstream downward for vertical take-off and the results are presented herein. The effects of a leading edge slat, ground proximity, end plate, and propeller position were also investigated. The tests were conducted in a static-thrust facility at the Langley Aeronautical Laboratory.—(1.10.2.2).

Similitude relations for free-model wind-tunnel studies of store-dropping problems. C. A. Sandahl and M. A. Faget. N.A.C.A. T.N. 3907. (*January* 1957).

Two methods, in which the model and prototype Mach numbers are assumed equal and the Reynolds number effects are assumed negligible, are presented for scaling store models for wind tunnel store-dropping studies. A brief description of the method of conducting store-dropping tests in the preflight jet of the Langley Pilotless Aircraft Research Station at Wallops Island, Va., is given.—(1.10.2.2×25.2).

HELICOPTER AERODYNAMICS

Distribution of normal component of induced velocity in lateral plane of a lifting rotor. W. Castles and H. L. Durham. N.A.C.A. T.N. 3841. (*December* 1956).

Values of the non-dimensional normal component of induced velocity in the lateral plane of a uniformly loaded lifting rotor are given in the form of graphs and tables. The necessary auxiliary equations are given so that the graphs or tables of the induced velocity ratios may be used to estimate numerical values of the normal component of induced velocity and the associated flow angle in the lateral plane of any given rotor or set of laterally disposed rotors.—(1.11.3).

Investigation of vertical drag and periodic airloads acting on flat panels in a rotor slipstream. R. A. Makofski and G. F. Menkick. N.A.C.A. T.N. 3900. (*December* 1956).

Tests have been conducted on the Langley helicopter test tower to determine the vertical drag and pressure distributions on flat panels mounted below a helicopter rotor. Calculations of the vertical drag by use of a strip-analysis procedure outlined in the paper and the assumption of a fully contracted wake agreed well with the experimental results over the range from 0·2 to 0·64 rotor radius beneath the plane of zero flapping.—(1.11.1).

TESTING AND INSTRUMENTS
See also THERMO-AERODYNAMICS

Mechanical design and fabrication of strain-gage balances. R. M. Hansen. AGARD Report 9. (*February* 1956).

Wire-strain-gauge-balance design concepts are considered from a practical standpoint. A typical balance illustrates how the concepts were applied in practice.—(1.12.6.2).

Mesure et enregistrement des mesures sur les balances aérodynamiques a jauges à fil résistant. M. Bassière. AGARD Report 14. (*February* 1956).

Discussion des conditions d'emploi des jauges à fil résistant dans les balances aérodynamiques. Description d'un ensemble de mesure utilisant une alimentation des jauges en courant continu et comportant un potentiomètre asservi spécial qui assure la correction des dérives dues aux thermocouples. Presented at the Eighth Meeting of the Wind Tunnel and Model Testing Panel, held from 20th to 25th February 1956 in Rome, Italy.—(1.12.6).

Some possibilities of using gas mixtures other than air in aerodynamic research. D. R. Chapman. N.A.C.A. Report 1259. (1956).

A study is made of possible uses in compressible-flow research of various gas mixtures having the same specific-heat ratio as air. Such mixtures require low wind tunnel power and have other possible applications in compressor research and firing-range research. Certain gas mixtures can be concocted which behave at wind tunnel temperatures dynamically similar to air at flight temperatures.—(1.12.1.3 × 1.2.3).

AEROELASTICITY

See also AERODYNAMICS—LOADS
—STABILITY AND CONTROL

Criteria for the prevention of flutter of tab systems. H. Wittmeyer and H. Templeton. R. & M. 2825. (1956).

The flutter characteristics are investigated for an idealised tab system in which the three degrees of freedom, normal translation of the lifting surface, rotation of the control surface, and rotation of the tab are represented. Specific cases of this idealised system represent similar idealised forms of the standard trimming, spring, servo, and geared tab systems. From the relationships existing between the systems, criteria for flutter prevention have been developed. The criteria are applicable to the stick-fixed condition (in the case of spring and servo-tabs), to the case with no aerodynamic balance on either control surface or tab, and to the case where the control surface is statically balanced about its hinge.—(2 × 1.6.3).

Flutter calculations on a resonance model delta wing. H. Hall. C.P. 260. (1956).

Resonance tests on a dural model delta wing are used as a basis for flutter calculations to determine the effect on the flutter characteristics of changes in structural inertias and stiffnesses. Forward movement of the inertia axis and increased stiffness of the wing spars are shown to be separately beneficial. The calculated flutter speeds are compared with flutter speeds given by formulae derived from earlier flutter tests on model delta wings in the wind tunnel and on ground launched rockets.—(2 × 33.2.3.2).

Results of two free-fall experiments on flutter of thin unswept wings in the transonic speed range. W. T. Lauten and H. C. Nelson. N.A.C.A. T.N. 3902. (*January* 1957).

Results of four thin, unswept, flutter aerofoils attached to two freely falling bodies are reported. Two aerofoils fluttered at a Mach number of 0·85, a third aerofoil fluttered at a Mach number of 1·03, and a fourth fluttered at a Mach number of 1·07. Results of calculations of flutter speed using incompressible and compressible air-force coefficients, including a Mach number of 1·0, are presented.—(2).

AIRCRAFT

Saunders-Roe Princess flying boat G-ALUN engineering appraisal. C. P. 280. (1956).

Assessments are given of most of the main installations provided, as well as of ease of launching, beaching and maintenance. Full reports on each of the main installations have been prepared by Saunders-Roe. The various aircraft systems and services are briefly described and assessed where possible, and items requiring further development and investigation are discussed.—(3.10).

AIRCRAFT OPERATION

Proposed initiating system for crash-fire prevention systems. J. C. Moser and D. O. Black. N.A.C.A. T.N. 3774. (*December* 1956).

The initiating system was designed to meet the requirements of such a system as determined by a study of data obtained from full-scale experimental and accidental aeroplane crashes. An example of the application of these requirements in the design of an initiating system for a twin-engined piston-powered aeroplane is given.—(5).

FUELS AND LUBRICANTS

*The evaporation of fuel sprays I—Theoretical treatment. G. W. Benson. N.A.E. L.R.*181. (*November* 1956).

Two models have been proposed which will predict the rate of evaporation of a spray in which the mutual effects of adjacent drops are important. The models make approximations and give relatively simple final equations of identical form, but slightly different numerical values for the parameters. More exact treatments are possible but they result in more complicated expressions. These expressions can be shown to reduce to the more simple form in the limiting case of low volatility sprays. The advantage of the present treatment is its simplicity and that it leads to the definition of evaporation parameters that should be useful in empirical work.—(14).

*Evaporation of fuel sprays II—Experimental work. G. W. Benson and R. J. Brisebois. N.A.E. L.R.*182. (*November* 1956).

A new technique for measuring the rate of evaporation of a spray is being developed. The method is based on the cooling produced when a spray evaporates adiabatically. Results obtained are consistent with a theoretical approach expounded in N.A.E. L.R.181. The apparatus can be easily modified to give psychrometric data from which it is possible to calculate diffusion coefficients of vapours in air.—(14).

HYDRODYNAMICS

Étude théorique et expérimentale de la stabilité des chambres d'équilibre situées en aval d'une galerie en charge alimentée par un canal a écoulement libre. S. Gerber. Pub. Sc. et Tech. 320. (1956).

Etude de la stabilité des oscillations des chambres d'équilibre branchées sur un canal à écoulement libre par l'intermediaire

d'une galerie en charge. Détermination des relations théoriques précisant les conditions à remplir pour que les oscillations du plan d'eau s'amortissent (canal infiniment long ou de longueur finie, sans ou avec pertes de charge, cheminées ordinaires ou à étranglement). Vérifications expérimentales et applications des relations établies.—(17.1).

Pressure losses of titania and magnesium slurries in pipes and pipeline transitions. R. N. Weltmann and T. A. Keller. N.A.C.A. T.N. 3889. (*January* 1957).

Experimental and calculated pressure losses are presented for Newtonian fluids and non-Newtonian slurries for laminar, transitional, and turbulent flow in straight pipelines and pipe transitions such as valves, 90° elbows, contractions, and expansion. Transition loss coefficients, which are independent of the flow rate in the pipeline even in laminar flow, were determined for these transitions. It was found that the transition loss coefficients for Newtonian fluids can be used in the calculations for the design of a pipeline system for the non-Newtonian slurries studied.—(17.1).

MANAGEMENT

Needed research for machine information systems. J. W. Kuipers. AGARD Report 47. (*February* 1956).

The difficulties which have arisen in using machines for documentation purposes are explained and their causes analysed. The need is emphasised for research on the nature of the units to be handled and lines are indicated along which research should be directed to overcome these difficulties.—(20 × 30).

MATERIALS

See also FATIGUE

A critical review of the mechanism of ageing in alloys based on the aluminium-zinc-magnesium system. I. J. Polmear. A.C.A. Report 59. (*August* 1955).—(21.1).

Shear strength at 75°F. to 500°F. of fourteen adhesives used to bond a glass-fabric-reinforced phenolic resin laminate to steel. J. R. Davidson. N.A.C.A. T.N. 3901. (*December* 1956).

Fourteen adhesives used to bond a glass fabric reinforced phenolic resin laminate to steel were tested to determine their shear strengths at temperatures from 75°F. to 500°F. Fabrication methods were varied to evaluate the effect of placing cloth between the faying surfaces to maintain a uniform bond-line thickness. One glass fabric supported phenolic adhesive was found to have a shear strength of 3,400 p.s.i. at 300°F. and over 1,000 p.s.i. at 500°F. Strength and fabrication data are tabulated for all adhesives tested.—(21.3).

MATHEMATICS

Incomplete time response to a unit impulse and its application to lightly damped linear systems. J. J. Donegan and C. R. Huss. N.A.C.A. T.N. 3897. (*December* 1956).

A study is made of the use of the incomplete time response to a unit impulse as a device to analyse lightly damped linear systems. The results indicate that such a system can be adequately described by an incomplete time response to a unit impulse which is computed from the incomplete-output time history (without the addition of an estimated end correction) and the complete-input time history. The incomplete response to a unit impulse may be used with Duhamel's integral to predict the response of the system to an arbitrary input up to at least 90 per cent of the cut-off time of the incomplete-output time response.—(22).

MECHANICAL ENGINEERING

Friction, wear, and surface damage of metals as affected by solid surface films. E. E. Bisson et al. N.A.C.A. Report 1254. (1956).

A summation is presented of N.A.C.A. results obtained from friction and wear investigations from 1946 to 1954. The results are consistent with theoretical predictions that solid surface films of low shear strength can serve to reduce both friction and surface damage. Metallic oxides can have very marked effects. Wear studies show that the ability of materials to form surface films is an important factor in wear. Solid lubricants (MoS_2 and graphite) are beneficial under severe operating conditions, including temperatures approaching 1,000°F.; both materials are, however, subject to oxidation at these temperatures.—(23.1).

Performance of 110-millimeter-bore M-1 tool steel ball bearings at high speeds, loads, and temperatures. W. J. Anderson. N.A.C.A. T.N. 3892. (*January* 1957).

Eleven bearings lubricated with a synthetic of the diester type were run at speeds to 14,000 r.p.m. and bearing temperatures to 678°F. Eight bearings failed in fatigue indicating that the fatigue life of M-1 bearings might be much shorter than the life (based on catalogue ratings) of S.A.E. 52100 bearings lubricated with mineral oil. Iron-silicon bronze and silver-plated iron-silicon bronze cages showed negligible wear, but the silver plate showed some tendency to blister and peel. Cast inconel coated with nickel oxide was not a satisfactory cage material at these temperatures and speeds.—(23.1).

METEOROLOGY

Ice prevention in a cloud of ice crystals. C. K. Rush. N.A.E. Note 14. (1956).

The formation of ice in clouds composed primarily of ice crystals is discussed. Heat requirements for ice prevention are presented for a number of typical meteorological conditions and it is concluded that these may be severe. Some suggestions for avoiding the formation of ice under these conditions are given and it is noted that there is a need for reliable data on the concentrations and characteristics of ice crystals which may be found in clouds.—(24).

MISSILES

See AERODYNAMICS—WINGS AND AEROFOILS

POWER PLANTS

Effect of ambient-temperature variation on the matching requirements of inlet-engine combinations at supersonic speeds. E. Perchonok and D. P. Hearth. N.A.C.A. T.N. 3834. (*January* 1957).—(27.1).

Analytical investigation of the effect of water injection on supersonic turbojet-engine-inlet matching and thrust augmentation. A. Beke. N.A.C.A. T.N. 3922. (*January* 1957).

Evaporation cooling by water injection in the subsonic diffuser was investigated.—(27.1).

REFERENCE LITERATURE

See MANAGEMENT

FATIGUE

Research on cumulative damage in fatigue of riveted aluminum alloy joints. J. Schijve and F. A. Jacobs. N.L.L. Report M. 1999 *included in N.L.L. Transactions Vol. XX.* (1955).

Two-step tests and interval tests were performed on 24 S-T Alclad riveted lap joints to study the cumulation of fatigue damage and to verify the linear cumulative damage rule. Available data on light alloy specimens are reviewed and compared with the results of the present investigation. Some general trends of the cumulative damage phenomenon are suggested. Some proposed cumulative damage rules are discussed. Some remarks are made on the life estimation of structures under service loading. Proposals for further investigation are made.—(31.2.3.2.2.2).

Fatigue tests on notched and unnotched sheet specimens of 2024-T3 and 7075-T6 aluminum alloys and of S.A.E. 4130 steel with special consideration of the life range from 2 to 10,000 cycles. W. Illg. N.A.C.A. T.N. 3866. (*December* 1956).

The notched specimens had theoretical stress-concentration factors of 2·0 and 4·0 and the mean loads were 0 and 20 or 50 k.s.i. It was found that repeated applications of stresses in the vicinity of the ultimate strength on notched and unnotched specimens produced failures in a much smaller number of cycles than might be inferred from previously published data. Ratios of fatigue strengths of unnotched specimens to those of notched specimens are given.—(31.2.2.3.1 × 31.2.2.2.1 × 21.2.0).